Jan 2000

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 2000	Technical Report

4. TITLE AND SUBTITLE
A comparison of 2 current-issue Army boots, 1 current-issue Marine Corps boot, and 3 second-generation prototype military boots: performance, efficiency, biomechanics, comfort and injury

5. FUNDING NUMBERS

6. AUTHOR(S)
Everett Harman, Peter Frykman, Clay Pandorf, Michael LaFiendra, Ty Smith, Robert Mello, John Patton, Carolyn Bensel and John Obusek

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Military Performance Division
US Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

U.S. Army Soldier Systems Center, Natick, MA

8. PERFORMING ORGANIZATION REPORT NUMBER
T00-8

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Medical Research and Materiel Command
Fort Detrick
Frederick, MD 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The experiment evaluated the physiological, biomechanical, and maximal performance responses of 10 male and 1 female soldiers wearing 2 current Army boots, 3 second-generation prototype Army boots, and the new current-issue Marine Corps boot. Physiological evaluation determined the rate of oxygen consumption for walking both with and without a 60-lb backpack and during unloaded running. Biomechanical analysis quantified gait, posture, and lower-extremity joint forces and torques. Maximal-speed runs both with and without the 60-lb backpack were timed on both straight and zigzag 400 m grass courses. Comfort and functionality questionnaires were administered to the volunteers after they walked 6 miles at 3 mph over pavement and wooded trail in each boot-type; blisters and other foot trauma were assessed post-march. Based on their overall performance, the boots were ranked from best to worst as follows: (1) Prototype 4, (2) Prototype 3, (3) Prototype 2, (4) Army combat boot, (7) Army jungle boot, (6) Marine Corps boot. The performance of all the boots is summarized in a table, and a list is provided of the best performer for each major evaluation variable.

14. SUBJECT TERMS
boot, evaluation, combat, jungle, load carriage, prototype, sole, Army, military, run, walk, march, oxygen consumption, VO2, energy cost, pressure, injury, risk, comfort, biomechanics, kinematics, kinetics, jump, rearfoot motion

15. NUMBER OF PAGES
82

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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BACKGROUND

As a follow-up to the military footwear research of Hamill and Bensel (6, 7, 8), described in the introduction section of this report, an applied research program in biomechanics was established to generate concepts for improved military boots. The program was approved as a Department of Army Science and Technology Objective to be conducted jointly by the U.S. Natick Soldier Center and the U.S. Army Research Institute of Environmental Medicine. The goals of the program were to identify concepts for military footwear that would improve the locomotor efficiency of the wearer and result in a reduction of stress-related injuries of the lower extremities compared with the standard-issue black leather combat boots. Requirements for improved boots were generated that addressed functional characteristics, such as durability under military field conditions, and biomechanical characteristics, such as impact properties. These requirements formed the basis of a request for proposals for design and fabrication of prototype boots. A group that included three footwear manufacturers was awarded the contract to produce prototypes. The lead contractor was Ro-Search, Inc., a division of Wellco Enterprises (Waynesville, NC), a major producer of military footwear. The other footwear manufacturers were Hyde Athletic Industries, Inc. (Peabody, MA) and Rocky Shoes and Boots, Inc. (Nelsonville, OH).

Five prototype concept boots were designed and produced by these companies. We conducted a study (10) comparing the performance of the five prototype boots, two current-issue Army boots, and five commercial hiking boots. The study assessed the physiological, biomechanical, and maximal performance responses of men wearing the various boots. Based on performance, efficiency, biomechanics, comfort, and injury we rated the boots as follows, from best to worst:

1.	Salomon Adventure 9 Ultralight (boot 12)	100
2.	Raichle Highline (boot 9)	90
Three-way tie:		
4.	Prototype 3 (boot 3)	84
4.	Prototype 4 (boot 4)	84
4.	Asolo Meridian (boot 11)	84
6.	Asolo AFX 535 (boot 10)	73
7.	Prototype 1 (boot 1)	70
8.	Prototype 2 (boot 2)	67
9.	Montrail Moraine (boot 8)	65
10.	Army combat boot (boot 6)	59
11.	Army jungle boot (boot 7)	51
12.	Prototype 5 (boot 5)	50

The poor performance of the current-issue Army combat and jungle boots justified the initiative to develop new standard-issue Army boots. Changes were made to prototype boots 2, 3, and 4 to improve their performance. We then initiated a follow-up experiment designed to compare the physiological, biomechanical, and maximal performance responses of soldiers to these second-generation prototypes, the current-issue Army combat and jungle boots, and the new current-issue Marine Corps boot. The results of that experiment are presented in this report.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

mph	miles per hour
psi	pounds per square inch
USARIEM	U.S. Army Research Institute of Environmental Medicine
USASSC	U.S. Army Soldier Systems Center in Natick, MA

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EXECUTIVE SUMMARY

The experiment evaluated the physiological, biomechanical, and maximal performance responses of 10 male and 1 female soldiers wearing 2 current Army boots, 3 second-generation prototype Army boots, and the new current-issue Marine Corps boot. Several different tests were performed on the volunteers while they wore each of the 6 boots. Physiological evaluation determined the rate of oxygen consumption for walking both with and without a 60-lb backpack and during unloaded running. Biomechanical analysis quantified gait, posture, and lower-extremity joint forces and torques. Maximal-speed runs both with and without the 60-lb backpack were timed on both straight and zigzag 400 m grass courses. Comfort and functionality questionnaires were administered to the volunteers after they walked 6 miles at 3 mph over pavement and wooded trail in each boot-type; blisters and other foot trauma were assessed post-march. All testing was performed at the U.S. Army Soldier Systems Center in Natick, MA, and on the roads and in the forest of the town of Natick, MA, during the early spring of 1998.

Following statistical analysis of the test results, the boots were assigned points according to their performance on the measures deemed most important. The following is the ranking (best to worst) of the boots tested:

Rank	Boot	Score
1.	Prototype 4	100
2.	Prototype 3	88
3.	Prototype 2	79
4.	Army combat boot	61
5.	Army jungle boot	51
6.	Marine Corps boot	50

Of the boots tested, the 3 prototypes, boots P2, P3 and P4, were markedly superior to the current-issue Army combat and jungle boots and the current-issue Marine Corps boot. The relatively poor performance of the current-issue military boots supports the current initiative to develop new standard-issue boots. Boot P4 was the best boot overall, by a good margin, and appears to be the best candidate tested for adoption by the Army. However, it is important to note that we did not perform some essential off-the-wearer boot tests, such as tests for resistance to wear, water, organic liquids, heat, flame, etc. Neither did we test how the boots function after being used for several months. Evidence from such tests should be combined with evidence from our experiments for overall boot evaluation.

The report includes tables showing the performance data of all the boots on the various tests performed. A summary table shows the point scores on all the key measures. In addition, a list is provided of which boot performed best on each major evaluation variable. The information provided in the report should enable boot designers and developers to make fact-based decisions regarding boot development and selection.

INTRODUCTION

At the beginning of Army basic training, every recruit is issued leather combat boots that are used for all training activities other than group calisthenics and running. Following basic training, soldiers wear their boots for many activities including field exercises, garrison work, combat scenarios, and actual combat. Essentially, the boot is used in all circumstances in which specialized footwear (safety shoes, cold weather boots, hot weather boots etc.) is not required. Army-issue boots differ from commercially available hiking boots in that the latter are used primarily for hiking while Army boots are used for running, jumping, climbing, crawling, marching, hiking, as well as for other activities. Also, hikers are largely expected to stay on trails and do some hill climbing on rocky surfaces, rocky surfaces, whereas soldiers may be required to take off-trail routes through dense forest, brush, mud, and water. In addition, the Army-issue boots are used in built-up areas, where soldiers encounter paved surfaces, stairways, and building interiors. Thus, unlike hiking boots, the Army boots are used for a variety of physical activities performed in a wide range of environments.

Hamill and Bensel (6) reviewed requirements that have been used to guide development of recent generations of the Army leather combat boots, and identified three levels of requirements. Primary requirements deal with the boots' ability to 1) enhance the locomotor capabilities of the wearer, 2) minimize the occurrence of lower extremity injury and pain, and 3) provide comfort. Secondary requirements include 1) the weight of the boot, 2) how high the boot comes up the ankle, 3) the design of the closures, 4) water resistance and 5) durability of the material. Tertiary requirements include the cost and rate of production. Incorporating these and other characteristics into a single item of footwear make development of Army boots a challenging undertaking.

Previous military footwear research has been aimed at developing recommendations for new designs. Biomechanical analysis of military boots has involved comparisons of military and commercial footwear via materials testing and human subject experimentation. Hamill and Bensel (6, 9) conducted biomechanical studies of military footwear focused specifically on identifying means of enhancing locomotor capabilities and reducing lower extremity injury rates. The goal of the work was to develop recommendations for future military footwear with regard to materials, design, construction, fabrication techniques, and any other aspects that would benefit the performance and lower extremity health of military personnel. The biomechanical analyses carried out by Hamill and Bensel, consisting of materials testing and human subject experimentation performed on military boots and commercial shoes and boots, generated recommendations for the design of future military footwear.

In the first phase of the biomechanical analysis of military boots, Hamill and Bensel (6) focused on material testing. The military footwear tested consisted of the current-issue black leather "combat boot" and the hot weather "jungle boot". The commercial items were a basketball shoe, a cross trainer, a hiking boot and a work boot. Hamill and Bensel used an impact tester on the combat and jungle boots and the commercial footwear to measure peak deceleration of the impact head, time to peak deceleration, and peak

pressure. Time to peak deceleration was defined as the amount of time from initial contact of the impact head with the shoe to the maximum deceleration. Peak pressure was defined as force per unit area exerted on the shoe by the impact head at the time of the maximum deceleration. In general, it was found that the jungle and combat boots had higher peak decelerations, shorter times to peak deceleration, and higher peak pressures than the commercially available shoes and boots. Thus, the Army-issue boots compared unfavorably to the commercial items. For all the footwear, there was lower peak deceleration and lower peak pressure in the heel as opposed to the fore-foot areas.

In the second phase of their research, Hamill and Bensel (7) determined how the Army and commercial footwear compared when worn by human subjects. The researchers tested the footwear during walks at three speeds: 1.15 m/s, 1.5 m/s, and 3.4 m/s. During the walks, the jungle and combat boots produced the highest peak impact forces. Further, the magnitudes of the propulsive peak were relatively large as compared to commercially available footwear. In contrast, vertical ground reaction force peaks during running were either essentially the same or lower for jungle and combat boots. The researchers also showed that heart rate did not vary significantly as a function of footwear during any locomotor activities. Men's oxygen consumption was not affected by footwear, but women's oxygen consumption did vary depending on which boot was being worn. There was no relationship between men or women's oxygen consumption and footwear mass or footwear hardness. Kinematic analysis revealed high ankle flexion velocities for jungle and combat boots possibly causing the straining of the long plantar ligaments.

In a similar experiment, Williams et al. (18) compared current-issue combat and jungle boots to commercially available boots, and to a hybrid boot composed of the outer sole of the jungle boot and a non-standard polyurethane sole. It was found that the commercially available boots tested superior to the standard issue jungle and leather combat boots on impact tests. On the performance tests, greater shock absorption and lower power requirements were obtained with the commercially available boots. These findings suggest that at least some commercially available boots embody characteristics that are superior to those of the standard-issue military boots.

Nigg et al. (15) found larger rear-foot angles (inversion) at foot strike with the harder midsoles and proposed that the angular differences associated with differences in midsole hardness reflected a protective mechanism. Also Clarke, Frederick and Hamill (3) found softer midsoles associated with greater maximum pronation and total rear-foot movement. McNitt-Gray (14) found that peak vertical ground reaction forces in a jump from 0.72 m are approximately six times body weight. Robinson, Frederick, and Cooper (16) found that the rigidity of stiffeners placed anterior and posterior to the lateral and medial malleoli affected the time to complete an agility course. The fastest course times were clocked when basketball shoes were worn, while the slowest times were produced when boots with stiffeners of the highest bending moment were used. In Hamill and Bensel's study (9), the footwear with the highest uppers - the work boot, combat boot, and jungle boot - resulted in longest time to complete the agility course. The longer time to complete the agility course may be due to the fact that the boots with the highest uppers were heavier, but this was not specifically reported. Also these three boots produced

more limited and rapid ankle dorsiflexion, suggesting the restriction on ankle motion inhibited rapid changes in direction and pace.

Cavanagh and Lafortune (1) reported that the amplitude of vertical ground reaction force during running is up to twice that occurring during walking. They reported vertical ground reaction forces of two to three times body weight at running speeds in the range of 4.12 to 4.87 m/s.

Knapik et al. (12) conducted a study to assess injuries associated with long road marches. Light infantry soldiers carried a 46 kg total load a distance of 20 km. Twenty four percent suffered one or more injuries, resulting in 44 days of limited duty. Foot blisters accounted for 35% of the total injuries making it the most common injury associated with the march. Blisters are generally caused by ill-fitting boots that rub against the skin (17).

In our previous study of 2 current-issue Army boots, 5 prototype military boots, and 5 commercial hiking boots, as to performance, efficiency, biomechanics, comfort and injury (10) we rated the boots from best to worst, as described in the Background section above. The poor performance of the current-issue Army combat and jungle boots justified the initiative to develop new standard-issue Army boots.

Following improvements made to 3 of the prototype boots, a follow-up experiment was designed to compare these second-generation prototypes to the current-issue Army combat and jungle boots, and to the new current-issue Marine Corps boot. In that study, described in this report, we evaluated the physiological, biomechanical, and maximal performance responses of 10 male and 1 female soldiers to the various boots. Physiological evaluation determined the rate of oxygen consumption when volunteers carried a 60-lb backpack load while walking in each type of boot. Biomechanical analysis quantified gait, posture, and lower-extremity joint forces and torques. Maximal-speed runs with and without a 60-lb backpack were timed on both straight and zigzag 400 m grass courses. Comfort and functionality questionnaires were administered to the volunteers after they walked 6 miles at 3 mph over pavement and wooded trail in each boot-type. Blisters and other foot trauma were assessed post-march. All testing was performed at the U.S. Army Soldier Systems Center in Natick, MA, and on the roads and in the forest of the town of Natick, MA, during the spring of 1998.

The 60 lb load selected for this study is supported by the U.S. Army field manual on foot travel (Department of the Army, 1990), which states that up to 72 lb may be carried on "prolonged dynamic operations." The 60 lb backpack weight falls within a range typical of Army field operations.

METHODS

BOOTS

Of the 5 prototype boots examined in our previous boot study (10), 3 were selected for further development and study. Those 3 boots were designated as boots 2, 3, and 4 in our previous study. They were modified (mainly as to the outer sole) to improve their performance and are designated as boots P2, P3, and P4 in this report to correspond to their numbers in the previous experiment, enabling easy identification. Prototype boots 1 and 5 from our previous experiment were dropped as candidates for further development. The 3 updated prototype boots are compared in this experiment to the current-issue Army combat boot (referred to as boot AC in this report), the current-issue Army jungle boot (referred to as boot AJ in this report), and the current-issue Marine Corps boot (referred to as boot MC in this report). Photographs of the 6 boots studied in this experiment (boots P1, P2, P3, AC, AJ, and MC) are shown in Figures 1-6.

It is extremely expensive to start production of any new boot. In a large production run, the initial costs are spread over the entire run, so that the cost per boot is relatively low. Because a prototype run is very limited in number, the cost per boot is extremely high. Making boots of different sizes multiplies a good part of the cost. To avoid prohibitive materiel costs for this study, the prototypes were made in only two sizes. Men's sizes 9 and 11 in regular width were selected because they are common shoe sizes in the United States.

The 3 Prototype Boots (Boots P2, P3, and P4)

In our previous boot study (10), the uppers of the 5 prototype boots were basically the same. Similarly, the uppers for the second-generation versions of prototype boots P2, P3, and P4, examined in this study, were also quite similar. The common uppers for the prototypes are described below, and their differing soles are described separately. Following that are descriptions of the remaining boots tested, including the current-issue Army combat and jungle boots, and the current-issue Marine Corps boot. The common features of prototypes 2-4 were as follows:

Last. All prototypes are made over MIL-5 lasts, the same last system used for fabrication of standard Army combat boots. However, the depth of the last was increased by 5/32 in, to allow for the thickness of a removable insert placed in the boots.

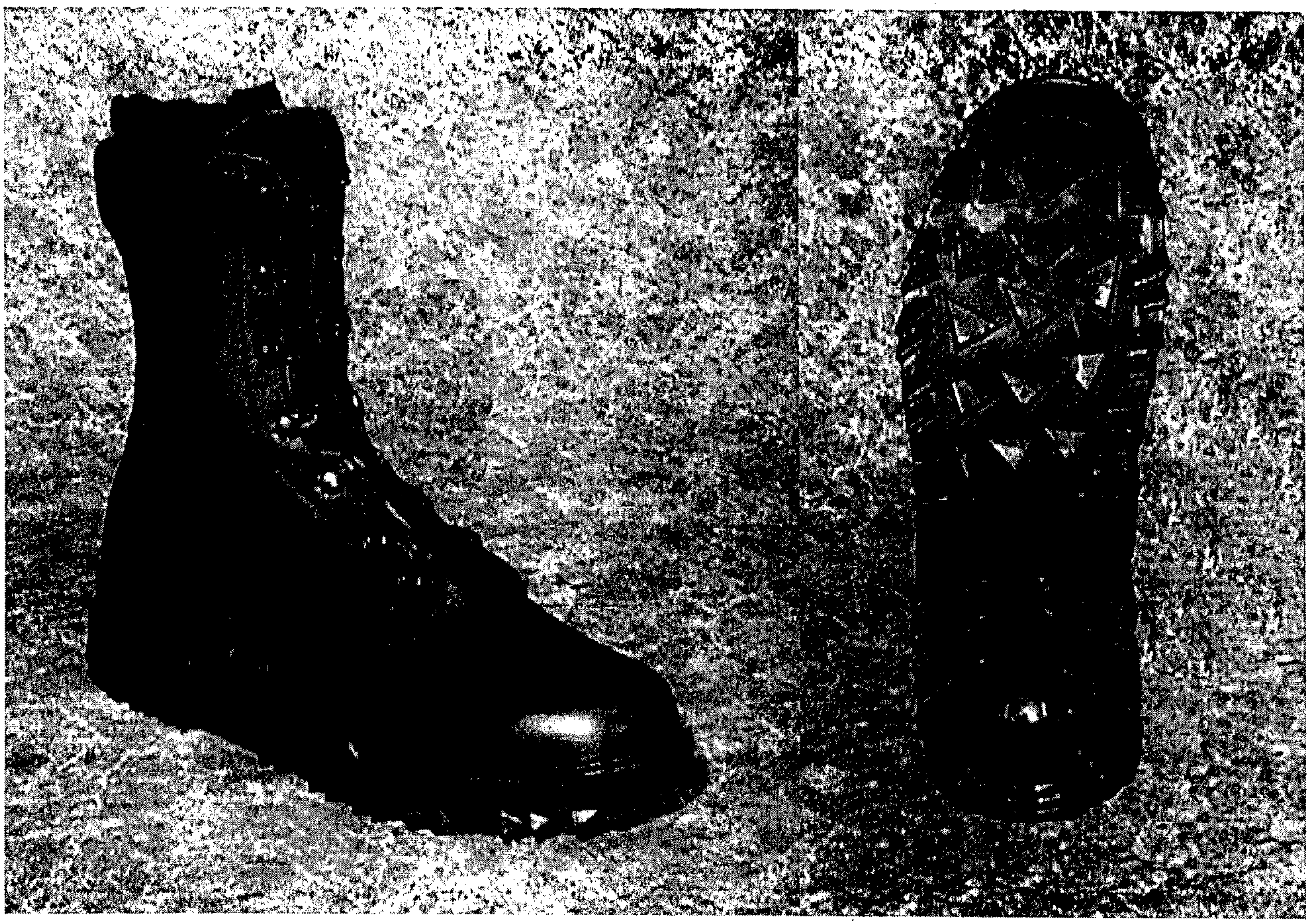

Figure 1. Boot P2 - second generation prototype 2 military boot

Figure 2. Boot P3 - second generation prototype 3 military boot

Figure 3. Boot P4 - second generation prototype 4 military boot

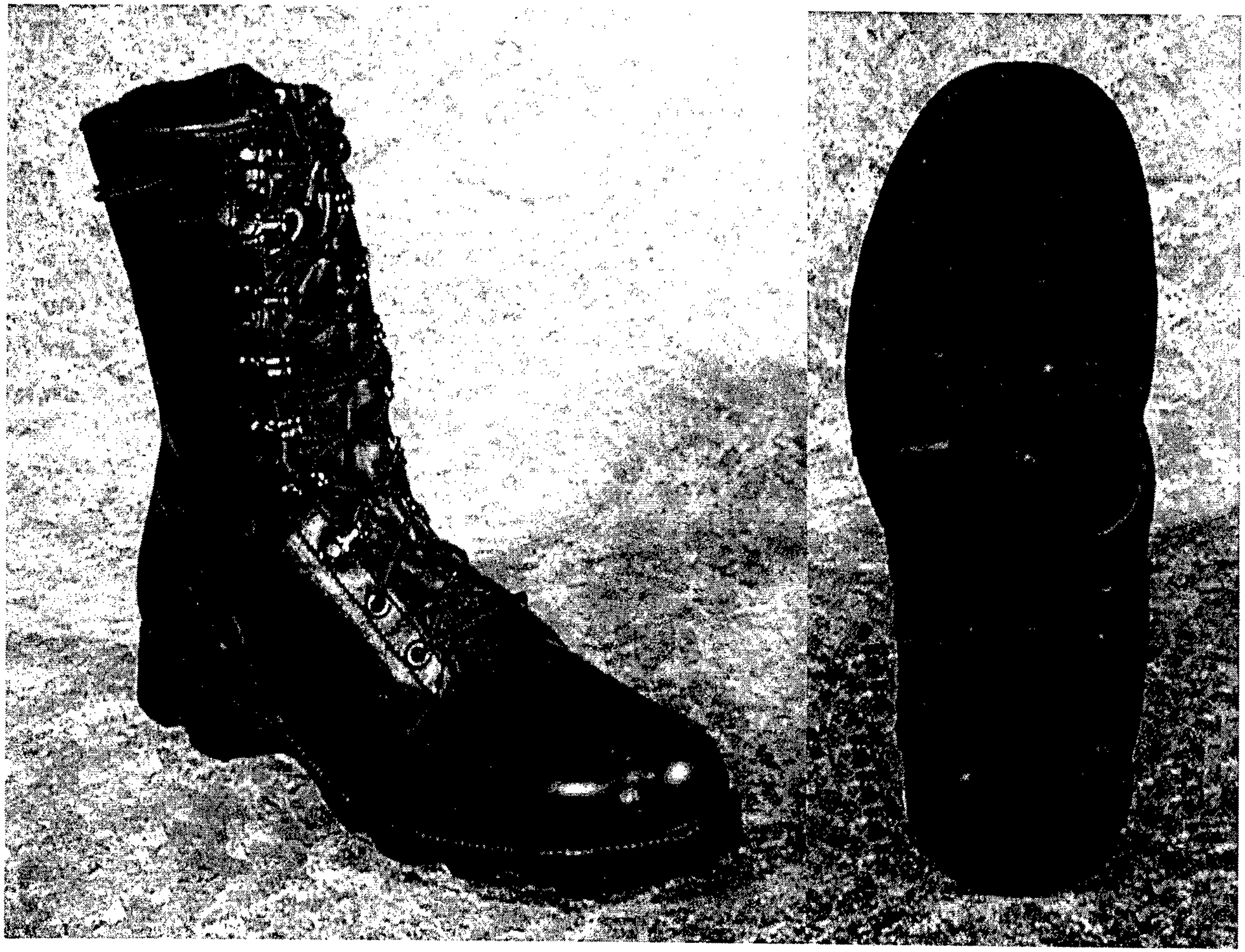

Figure 4. Boot AC - current-issue Army boot, commonly referred to as "Combat Boot"; officially designated as Boot, Combat, Mildew and Water resistant, Direct Molded Sole.

Figure 5. Boot AJ - current-issue Army boot, commonly referred to as "Jungle Boot"; officially designated as Boot, Hot Weather, Type I, Black, Hot-Wet.

Figure 6. Boot MC - current-issue Marine Corps boot.

Upper. All prototypes have an identical upper, which is similar in design to the upper on the standard black leather combat boot. However, the foam in the padded collar on the prototypes is thicker than that on the standard boot and the collar cover on the prototypes is a soft glove leather. The finished height on a size 9R prototype is 10 in, about 1/2 in shorter than the height of the standard leather boot in the same size. A softer temper leather is used for the upper of the prototypes, which is more flexible than the leather used in the standard boot. The interior of the vamp of the prototypes is lined with an absorbent material, Aero-Spacer Dri-Lex®. The standard leather combat boot does not have an interior lining. The prototypes have a two-piece backstay and counter pocket. On the standard boot, there is a combined backstay and counter pocket, made out of one piece of leather. The only change to the uppers of the first generation prototypes tested in our previous boot study in going to the second-generation prototypes tested in this study is a slight alteration in the quarter pattern, resulting in a greater separation between quarter edges when the boot is laced up on the leg.

Removable Insert. There is a molded, contoured, polyurethane insert with a Cambrelle cover in prototypes 2 and 3, but not in prototype 4. The insert is made of polyurethane polyether molded directly to a Cambrelle top cloth. This is the same insert used in the standard leather boot.

Soles. The soles for the 3 prototypes were all different and are described below:

Prototype 2 (boot P2):
This prototype is flat-lasted with a cemented-on sole. It has a unit sole constructed by cementing a pre-molded polyurethane midsole to a rubber, pre-molded cup outsole.

The midsole has the following characteristics:
Thickness: 1 in at back of heel, tapering off to a point halfway toward the front of the sole, where the thickness is 7/16 in
Density: .41 g/cm^3
Hardness: 65-68 Shore C
The insole is a four-iron leather insole.

Note: There were two changes made to the sole of prototype boot 2 in going from the first generation, examined in our previous boot study (10) to the second-generation, examined in the present boot study. One was a redesign of the outsole pattern to increase the size of the lugs at the heel and toe areas. The other was an increase of the midsole thickness at the fore-foot of the shoe.

Prototype 3 (boot P3):
This prototype is flat-lasted with a direct-injected polyurethane mid-sole and a pre-molded high wall rubber cup tread outsole.

The midsole is polyurethane with the following characteristics:
Thickness: From 1/4 in at center of foot to 3/8 in at edge of foot

Density: .60 g/cm^3
Hardness: 50 Shore A ± 5
The insole is a four-iron leather insole.

Note: The only change made to the sole of prototype boot 3 in going from the first generation, examined in our previous boot study (10), to the second-generation, examined in the present boot study was a new outsole pattern with enlarged center cleats.

Prototype 4 (boot P4):
This prototype is constructed using the Process 82 Comfort Welt® construction. The key feature of this construction is the use of a welt that has been attached previously to accomplish the lasting of the upper without the need for a structural insole. The "welt lasting" is performed on the mold last itself, and once the upper has been formed over the mold last, the sole is molded and vulcanized directly to the welt and to the lasting edge of the upper. In the process of construction, a cavity is formed in the sole.

A Comfort Core® insert is used in this prototype. This is an insert that is molded to match the cavity formed in the sole. The insert also has a molded, contoured top portion with a socklining cover.

The insert has the following characteristics:
Thicknesses: Center section of foot: 0.48 in. From center section to edge: 0.24 in. Section under heel: 1.00 in.
Density: .40 g/cm^3
Hardness: 26 Shore A

Note: The only change made to the sole of prototype boot 4 in going from the first generation, examined in our previous boot study (10), to the second-generation, examined in the present boot study was a new outsole pattern with deeper lug depth.

Current-Issue Army Combat Boot (Boot AC)

This boot is officially called Boot, Combat, Mildew and Water Resistant, Direct Molded Sole. Its upper, which is unlined, is fabricated of chrome tanned, grain-out, cattle hide leather, treated for mildew and water resistance. The upper has a rigid toe-box, made of Surlyn®, a one-piece, combined backstay and counter, and a padded collar. The heel counter is made of leatherboard. The boot closure system is a combination of eyelets and closed loops. The rubber outsole has a deep lug design, designated as the Trac Shun® pattern. The outsole is direct-molded to the leather insole using a method of vulcanization. A zinc-coated steel shank extends from the middle of the heel through the arch and ends just back of the ball area. The boot has a removable Poron® insert that extends from heel to toe, made of closed-cell urethane foam with a fiberboard backing.

Current-Issue Army Jungle Boot (Boot AJ)

This boot is officially called Boot, Hot Weather, Type I, Black, Hot-Wet. The forefoot part of the upper is leather as is the area along the closure system. The rest of the upper is nylon Cordura®. The entire upper on this boot is unlined. Two screened eyelets are set in the upper leather in the medial side of the boot in the waist area to facilitate water drainage. Nylon tape (1 inch) is on the back of the boot (backstrap area) and around the collar. A nylon tape (2 inch) also runs diagonally across the ankle. The toe box is the same as in the combat boot, as are the heel counter and Poron® insert. A Panama® tread pattern outsole is direct-molded to the leather insole. A 0.28 cm stainless steel plate is inserted between the leather insole, which is split in half and resewn around the edges. The plate extends the entire length of the boot. The steel shank is the same as in the combat boot.

Marine Corps Infantry Boot (Boot MC)

This boot has a toe-up lace closure with a "V" notch in the placket. The upper is made of breathable, water proof, grain out, mildew resistant, black leather and Cordura® nylon. The upper has a comfort top band and is lined with bootie made from a four-layer waterproof-breathable lining materials package composed of the outer nylon layer with a polyester polyurethane open cell foam layer that is heat-bonded to it. The next layer in the sandwich is the waterproof, breathable, plastic film made of polytetraflouroethylene and is bonded to the previous foam layer. The innermost layer of this materials package is a thin layer of nylon tricot knit. The midsole is made of polyether polyurethane and is direct-molded to the upper of the boot. The rubber outsole is black, non-marking, oil-resistant, and is glued to the midsole to facilitate resoling. The boot has a full shank made of fiberglass and a toe box made of Surlyn® resin.

The Marine Corps boots tested in this experiment were manufactured by Belleville Shoe Manufacturing Company (Belleville, IL). However, there are three other manufacturers of the Marine Corps boot, and there is enough leeway in the boot specifications to allow minor construction variation between boots made by the different manufacturers, related to their specific manufacturing techniques rather than to differences in materials.

Table 1 provides various information about the 6 boots studied.

Table 1. Descriptive information on the boots tested (data for size 9 regular)

Boot	Boot type	Weight per pair		Height	
		kg	lb	cm	in
P2	Prototype 2	1.70	3.75	25.6	10.08
P3	Prototype 3	1.79	3.94	25.4	10.00
P4	Prototype 4	1.68	3.70	25.2	9.92
AC	Army Combat boot	1.86	4.09	26.0	10.24
AJ	Army Jungle boot	2.01	4.42	23.5	9.25
MC	Marine Corps boot	1.78	3.92	25.2	9.92

RESEARCH VOLUNTEERS

Because only men's sizes 9 and 11 boots were available for testing, only volunteers who wore men's size 9 or 11 were recruited for the experiment. Each volunteer tried on the test boots to make sure they fit. It was difficult to find the required number of volunteers that wanted to do the study, had the available time, and fit into the boots. Therefore, both permanent party test volunteers and military employees of USARIEM and USASSC were accepted. Some of the volunteers had sedentary jobs, but more physically demanding jobs were represented as well. Table 2 shows some basic information about the volunteers, including their habitual physical activity levels.

The principal investigator or an assisting investigator briefed all potential research volunteers. Informed consent was obtained from those who chose to volunteer. Because several of the tests, such as the 6-mile backpack hike, were administered to each volunteer only once per week, the testing of all 6 boots took each volunteer at least 6 weeks of actual testing. There were 3-5 test sessions per week. Typically, each test session took 1-3 hours, which included testing, waiting for other volunteers to be tested, and resting between trials.

Table 2. Subject characteristics (n= 10 male, 1 female)

Subject	Gender	Rank	Age (years)	Mass (kg)	Ht (cm)	MOS	Activity score
1	Male	E-2	19	71.8	174.2	Medic	3
2	Male	E-2	22	86.9	171.5	Administration	1
3	Male	E-4	24	80.2	171.2	Cook	2
4	Male	E-4	34	91.4	181.2	Medic	3
5	Male	E-3	20	75.3	178.4	Medic	4
6	Male	E-4	27	83.2	172.7	Infantry	3
7	Female	O-3	38	70.7	176.7	Psychologist	3
8	Male	E-5	28	80.2	172.0	Lab tech	2
9	Male	E-4	22	76.9	172.7	Lab tech	2
10	Male	E-4	29	83.6	180.8	Administration	3
11	Male	E-5	28	81.6	175.2	Lab tech	2
Mean (SD)			26.5(5.9)	80.2(6.2)	175.1(3.7)		2.5(0.8)

Activity score: 0 = sedentary, 4 = very physically active

THE TEST BATTERY

Table 3 provides a summary of the tests performed by volunteers while wearing each of the 6 boots studied.

Table 3. The tests administered

Test Procedure	unloaded	with 60 lb backpack
rate of oxygen uptake, 3 mph walking	+	+
rate of oxygen uptake, 6 mph running	+	
biomechanical analysis	+	+
6 mile hike		+
400 m straight grass run	+	+
400 m zigzag grass run	+	+

+ = test administered

Physical Performance

One of the most critical factors to be considered in evaluating soldier/equipment interaction is the effect of the equipment on the performance of tasks by the soldier in scenarios involving the preparation for and engagement in combat.

Timed 400 m Grass Runs. Because the speed at which a soldier can run can greatly affect both his chances of avoiding injury on the battlefield and the effectiveness of the fighting unit, timed 400 m runs were included in the testing. The research volunteers were timed during maximal-speed runs over a 400 m straight grass course and a 400 m zigzag grass course while carrying and not carrying a 60 lb backpack. Timing was accomplished by 2 experimenters using hand-held stopwatches.

Physiology

Rate of Oxygen Consumption. For volunteers eating a normal mixed diet, the rate of oxygen consumption is closely related to the rate of energy utilization. Thus, in order to determine if the boots differ as to the amount of energy required to walk or run in them, the rate of oxygen uptake of the volunteers was measured while they walked on a level treadmill at 3.0 mph in each of the 6 test boots, both while unloaded and while carrying a 60 lb backpack. They were also tested while running unloaded at 6 mph. The volunteers had to wear a facemask or mouthpiece by which their expired air was collected and analyzed. The custom-made oxygen-uptake analysis system incorporated an air-flow meter, oxygen analyzer, carbon-dioxide analyzer, pulse counter, and Hewlett-Packard desktop computer and printer which could determine and print out every 30 seconds the rate of oxygen consumption and ventilation per minute expressed both in absolute terms and relative to the individual's body mass. The

walking or running duration per test speed was about 5 minutes to allow the volunteer to reach steady-state oxygen uptake.

Biomechanics

Kinematics and Kinetics. Both without a load and while carrying a 60 lb backpack, the volunteers walked at 3.5 miles per hour across a force platform, within the field of view of six Qualisys (Glastonbury, CT) cameras while walking in each of the 6 different boots. They were also monitored while running without a load at 6.5 mph in each of the boots. Biomechanical analysis of the camera data was performed using both Qualisys and custom software.

During the biomechanical testing, volunteers wore the standard Army physical training uniform, consisting of gray T-shirt and shorts, and the test boots. Spherical reflective markers approximately one inch in diameter were affixed to the skin and boot using double-sided tape. Markers were placed on the right side of the body at the base of the 5th metatarsal, lateral malleolus of the ankle, lateral femoral condyle of the knee, greater trochanter of the hip, acromion process of the shoulder, zygomatic arch of the head, lateral epicondyle of the elbow, and the radial styloid process of the wrist. In order to detect rear-foot motion, two markers were placed on the dorsal surface of the calf in line with the Achilles tendon, and two other markers were placed on the rear of the shoe, vertically bisecting the heel area from a rear view.

Volunteers walked both with and without a backpack at 3.5 mph and ran without a backpack at 6.5 mph along a level 15-foot long walkway paced by a custom-built system that cued the volunteer to the appropriate walking or running speed by a motor-driven striped cord next to the walkway moving at the designated speed. For the walking trials, an M16A1 mockup was carried in the port arms position. An electronic timing device (Brower Timing Systems, Salt Lake City, UT) insured that volunteers walked across the force plate at $\pm$5% of the designated speed. Trials during which the walking or running speed was not within 5% of the designated speed were discarded, and the trial was repeated. A video motion analysis system (Qualisys, Glastonbury, CT) using six cameras recorded the body movements of the volunteers in three dimensions as they crossed a force platform (AMTI, Newton, MA) mounted flush with the floor. The sampling frequency of the cameras was 60 Hz. As the volunteer stepped on the plate, a computer with an internal analog-to-digital converter board digitized and recorded voltages from the force platform proportional to the ground reaction forces. The sampling frequency of the system was 1,000 Hz. Three trials were conducted for each experimental condition. The unloaded and loaded walking, and unloaded running conditions for each boot were all tested in a single session, with the volunteers resting between trials as needed and having a 15-min rest break after each block of trials.

Under the assumption of bilateral symmetry, segmental movement data for the left side of the body was generated by phase shifting the right side data by 180°. A 12-segment model of the human body was constructed (two feet, two shanks, two thighs, two forearms, two upper-arms, a trunk and a head), and the mass inertial properties of

the segments were taken from estimates given by Dempster (4). A custom-written software program performed a standard link segment analysis frame-by-frame for a single stride. The single stride selected for analysis was centered on the point when the right foot struck the force plate. The stride was defined as that portion of the gait cycle from the point in time at which the right foot crossed in front of the left leg to the point in time at which the right foot next crossed in front of the left leg. The custom program calculated the location of the body center of mass as described by Winter (19) and plotted its coordinates for each frame of video data. The program also determined stride length, stride frequency, and body segment displacements, velocities, and accelerations. Joint reaction forces at the ankle, knee, and hip were calculated using inverse dynamics detailed by Winter (19).

Rear-foot angle was defined as the rear-view deviation in degrees between the line formed by the 2 markers in line with the subject's Achilles tendon and the 2 markers vertically bisecting the shoe heel area, with a negative angle indicating supination, and a positive angle pronation.

The trunk angle was defined as the angle between the trunk segment and the vertical axis. For a subject facing towards the right, the trunk angle is positive measured clockwise from the vertical and negative measured counter-clockwise from the vertical. The hip angle was defined as the angle between the thigh segment and the plane defined by the segment connecting right and left hips with the trunk segment. The knee angle was defined as the angle between the thigh and shank segments, and the ankle angle was defined as the angle between the shank and foot segments.

Because the duration of a single stride varied across subjects, it was necessary to normalize the differing time scales to allow for the direct comparison of the timing of events within the gait cycle across subjects. This was accomplished by expressing the time course of all the biomechanical variables as a percentage of the stride cycle.

Jump landing tests were conducted with the volunteer wearing the same set of markers as used during the walking and running biomechanical tests. A 24-inch high wooden box was placed adjacent to the force platform. The unencumbered volunteer stood atop the box in an upright position. Upon signal from an experimenter, the volunteer stepped straight out over the force platform and dropped to its surface. Volunteers were specifically instructed to neither jump upwards nor downwards when leaving the box, but rather to step straight out and drop, allowing the knees to flex during the shock absorption phase of landing, and achieving an upright position on the platform without bouncing up and down.

Comfort and Injury Risk Assessment

The comfort and risk of injury of each of the boots was assessed by having the volunteers walk 6 miles in each pair of boots while carrying a 60-lb backpack. The volunteers walked in a group and were paced at 3 mph. The first 1.5 miles was on paved road, after which the volunteers rested for 10 minutes. They then entered a forest and walked 3 miles on a moderately hilly wooded trail. After another 10-minute rest, they walked 1.5 miles back to the starting point. Following each hike the volunteers' feet were examined for blisters and chafing of the skin. The volunteers filled out a questionnaire concerning boot comfort (Appendix A).

EXPERIMENTAL DESIGN AND ANALYSIS

A balanced-order experimental design was used to ensure that none of the boots was more likely than any of the others to be tested earlier or later during the course of the experiment, thereby avoiding order effects due to learning, physical conditioning, fatigue, boredom, etc. The statistical analysis for each variable involved a 2-way ANOVA that looked at the main effects of boot (6 levels) and load (2 levels), as well as boot-load interaction. When an ANOVA identified a boot main effect, a Duncan post-hoc test was performed to identify significant differences between boots.

ENVIRONMENTAL IMPACT

Testing and training for this study were conducted indoors and outdoors at USARIEM and USASSC, and on Natick public streets, roads, and recreational land, after securing permission from town authorities. The study involved little or no airborne emission, waterborne effluent, external radiation, outdoor noise, or solid bulk waste disposal, thereby complying with existing federal, state, and local laws and regulations (AR 200-2 Categorical Exclusion A-11).

The field tests and road marches were conducted with 11 military volunteers from USARIEM and USASSC. All lived at the existing barracks at USASSC or in their habitual residences in and around the town of Natick, MA. Neither the living arrangements nor the experimental activities had a significant impact on the environment (AR 200-2 Categorical Exclusion A-19).

RESULTS

In all the tables in this section, a statistically significant difference between boots is indicated by absence of the same superscripted letter. However, this notation does not apply to differences across conditions, as in walking in the loaded vs. unloaded condition.

PHYSICAL PERFORMANCE

Timed 400 m Grass Runs

Table 4 shows that, on the straight grass 400 m course, there were no significant differences between run times without a load. With the 60 lb pack, boots AC and AJ produced the fastest mean times for the course, while boot MC produced the slowest mean time. Overall, addition of the load increased run time by about 34%.

Table 4. Run times (s) for 400 m straight grass course, mean (SD)

Boot	With no load	With 60 lb backpack
P2	96.26 [a] (12.62)	133.41 [a,b] (18.91)
P3	97.83 [a] (15.23)	132.96 [a,b] (16.67)
P4	96.73 [a] (11.97)	132.87 [a,b] (20.88)
MC	98.73 [a] (12.09)	138.51 [a] (20.23)
AC	98.32 [a] (10.85)	131.75 [b] (16.71)
AJ	100.13 [a] (14.68)	130.09 [b] (20.74)

Different letters indicate significant differences ($p \leq 0.05$)

On the 400 m zigzag course (Table 5), there were no significant differences among the different boots as to run time, both with and without the 60 lb backpack, although it may be worthy of note that the Marine Corps boot produced the slowest means on both tests. Overall, addition of the load increased run time on the zigzag course by about 26% compared to the 34% increase for the straight course. It is notable that run times for the zigzag course were slowed less by addition of the load than were run times for the straight course. Looking at it another way, going from the straight course to the zigzag course increased run time by 21% for the unloaded condition, and 15% for the loaded condition. Once slowed down by the load, zigzagging doesn't slow the runner much more. Apparently, on the straight run, for which power output (force· velocity) is the limiting factor, velocity must decline as force (due to the pack weight) increases. However, on the zigzag run, adherence of the boot sole to the ground is critical to withstanding the centrifugal force of running around a curve. Since centrifugal force is proportional to velocity squared, the slower loaded runner needn't decelerate as much in the curve as does the faster unloaded runner to avoid breaking traction.

Table 5. Run times (s) for 400 m zigzag grass course, mean (SD)

Boot	With no load	With 60 lb backpack
P2	118.22 [a] (14.53)	155.12 [a] (19.35)
P3	117.95 [a] (9.87)	152.06 [a] (19.03)
P4	116.5 [a] (12.80)	151.95 [a] (23.05)
MC	121.17 [a] (12.48)	157.60 [a] (22.73)
AC	120.48 [a] (10.39)	151.76 [a] (20.03)
AJ	119.23 [a] (15.16)	151.75 [a] (24.62)

Different letters indicate significant differences ($p \leq 0.05$).

PHYSIOLOGY

Rate of Oxygen Consumption

There were no significant or notable differences among the boots as to rate of oxygen consumption relative to body mass during unloaded walking, walking with the 60 lb pack, and unloaded running (Table 6).

Table 6. Rate of oxygen consumption relative to body mass (ml/kg/min), mean (SD)

Boot	Unloaded walking at 3.0 mph	Walking with 60 lb backpack, at 3.0 mph	Unloaded running at 6.0 mph
P2	17.05 [a] (0.91)	22.61 [a] (2.47)	42.88 [a] (2.90)
P3	16.99 [a] (1.07)	22.23 [a] (2.19)	42.50 [a] (2.23)
P4	17.12 [a] (1.24)	22.14 [a] (2.05)	42.83 [a] (2.96)
MC	17.48 [a] (1.42)	22.46 [a] (1.79)	43.21 [a] (2.58)
AC	17.36 [a] (1.12)	23.09 [a] (2.26)	42.86 [a] (2.37)
AJ	17.35 [a] (0.88)	22.42 [a] (1.60)	42.87 [a] (2.70)

Different letters indicate significant differences ($p \leq 0.05$)

Table 7 shows the rate of oxygen consumption relative to body-plus-load mass during unloaded walking, backpack load carriage, and unloaded running. The similarity in the means between the unloaded and loaded walking conditions show that the increase in oxygen consumption during load carriage is in direct proportion to the increase in load above body weight. In the previous table, rate of oxygen consumption was divided by body mass of the volunteer with shorts and T-shirt but no shoes. In this table, rate of oxygen consumption is divided by mass of the body-plus-load, including clothing and footwear. That is why the values for unloaded walking and running in this table are slightly less than in the previous table. There were no significant differences between boots in rate of oxygen consumption relative to body-plus-load mass during unloaded walking, backpack load carriage, and unloaded running.

Table 7. Rate of oxygen consumption relative to body-plus-load mass (ml/kg/min), mean (SD)

Boot	Unloaded walking at 3.0 mph	Walking with 60 lb backpack, at 3.0 mph	Unloaded running at 6.0 mph
P2	16.69 [a] (0.93)	16.53 [a] (1.67)	41.94 [a] (2.78)
P3	16.62 [a] (1.10)	16.26 [a] (1.53)	41.59 [a] (2.11)
P4	16.75 [a] (1.19)	16.19 [a] (1.42)	41.91 [a] (2.89)
MC	17.05 [a] (1.36)	16.49 [a] (1.27)	42.15 [a] (2.51)
AC	16.93 [a] (1.11)	17.06 [a] (2.25)	41.82 [a] (2.39)
AJ	16.95 [a] (0.84)	16.41 [a] (1.06)	41.88 [a] (2.56)

Different letters indicate significant differences ($p \leq 0.05$)

BIOMECHANICS

Motion Analysis of Backpack Walking

Kinematics. Greater front-back acceleration of the body center-of-mass while walking (Table 8) may be considered less desirable because it can reflect jarring of the body and higher forces. On the other hand, the greater acceleration can mean that the shoe does not dampen ground reaction forces, allowing better acceleration and deceleration in emergency maneuvers. As to front-back acceleration during unloaded walking, boot AJ produced the lowest acceleration, while boot AC produced the highest. There were no significant differences between boots as to front-back acceleration of the body during carriage of a 60 lb backpack.

Table 8. Maximum front-back acceleration (m/s^2) of the body center-of-mass while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	$3.34^{a,b}$ (0.70)	$3.60^{a,b}$ (1.26)	3.62^{a} (1.16)	$3.58^{a,b}$ (1.14)	3.65^{a} (0.95)	3.14^{b} (0.75)
60 lb pack	3.45^{a} (0.77)	3.34^{a} (0.84)	3.70^{a} (1.34)	3.65^{a} (0.78)	3.72^{a} (0.95)	3.49^{a} (1.12)

Different letters indicate significant differences ($p \leq 0.05$)

It is difficult to place a value judgment on stride length during walking (Table 9). While a greater stride length can contribute to a higher top speed, there is no apparent advantage of a longer stride length during walking at submaximal speed. During the tests of unloaded walking, boot MC produced the longest stride length, while boot P4 produced the shortest stride length. Under the 60 lb backpack load, boot MC again produced the longest stride length, while boot AJ produced the shortest stride length.

Table 9. Stride length (m) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	$1.690^{a,b}$ (0.059)	$1.687^{a,b}$ (0.059)	1.664^{b} (0.064)	1.702^{a} (0.062)	$1.673^{a,b}$ (0.071)	$1.687^{a,b}$ (0.063)
60 lb pack	$1.654^{a,b,c}$ (0.087)	$1.647^{b,c}$ (0.069)	$1.662^{a,b}$ (0.060)	1.680^{a} (0.088)	$1.657^{a,b,c}$ (0.046)	1.631^{c} (0.055)

Different letters indicate significant differences ($p \leq 0.05$)

The percentage of the stride under double support (Table 10) usually increases with the amount of weight carried (Martin and Nelson, 1986). This means that both feet are concurrently on the ground a greater percentage of the time. The adjustment is considered desirable because double support spreads the load over two feet, thereby improving balance and reducing the forces and torques experienced by each leg individually. On the other hand, increased time in double support generally means a shorter stride and greater energy cost. However, in this study there were no significant differences in the energy cost of walking, either with or without the load, even though there were significant differences in percentage of stride spent in double support. Without the load, boot P4 produced the greatest percentage of time in double support, while boots P2 and P3 produced the lowest percentages in double support. With the 60 lb pack, there were no significant differences between boots as to percentage of the stride spent in double support. A greater percentage of the stride was spent in double support when the load was carried than without it.

Table 10. Double support duration (% of stride) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	11.8[b] (1.01)	11.9[b] (2.05)	12.9[a] (2.16)	12.1[a,b] (1.69)	12.2[a,b] (2.10)	12.2[a,b] (1.87)
60 lb pack	14.3[a] (1.83)	14.2[a] (2.12)	14.3[a] (1.73)	13.7[a] (2.14)	13.8[a] (1.29)	14.6[a] (1.64)

Different letters indicate significant differences ($p \leq 0.05$)

Minimum sagittal plane ankle angle during walking (Table 11) can indicate resistance of the boot to ankle dorsiflexion, a larger minimum angle indicating greater resistance because it means the ankle does not bend as much. Boots P2, P3, P4, and AJ produced the greatest minimum angles suggesting greater resistance to ankle dorsiflexion, while boot MC produced the smallest minimum angle, suggesting less resistance to ankle dorsiflexion.

Table 11. Minimum sagittal plane ankle angle (deg) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	104.0[a] (6.24)	103.6[a] (6.45)	104.5[a] (6.76)	101.2[b] (7.19)	102.6[a,b] (5.97)	104.9[a] (7.36)
60 lb pack	103.7[a] (6.83)	103.9[a] (5.85)	103.4[a,b] (8.43)	101.2[b] (7.24)	103.2[a,b] (6.08)	104.4[a] (7.76)

There was a significant ($p<=0.05$) boot by load interaction

The results for sagittal plane ankle angle range while walking at 3.5 mph indicate total resistance by the boot to sagittal plane ankle motion, which can include either ankle dorsiflexion or plantarflexion or both. Boot MC produced a significantly smaller range of sagittal plane ankle motion than all the other boots, which did not differ significantly from each other, which means that it was the most restrictive boot to sagittal plane ankle motion. Because boot MC allowed the greatest ankle dorsiflexion of all the boots (Table 12), boot MC must be restrictive by resisting ankle plantarflexion.

Table 12. Sagittal plane ankle angle range (deg) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	30.0[a] (2.83)	30.2[a] (2.82)	29.9[a] (3.86)	28.0[b] (3.06)	30.0[a] (3.18)	29.3[a] (4.00)
60 lb pack	31.7[a] (3.66)	32.5[a] (3.46)	32.6[a] (5.76)	29.7[b] (3.06)	31.7[a] (3.41)	31.4[a] (3.94)

There was a significant (p<=0.05) boot by load interaction

Excess rear-foot motion during walking is considered undesirable because, when the ankle pronates or supinates excessively, potentially injurious torques in the frontal plane are transmitted up the leg to the knee and hip. Table 13 shows that all the boots produced supination. There was no significant difference between the boots as to minimum rear-foot angle during unloaded walking. However, during loaded walking, boots P4 and AC produced the most supination.

Table 13. Minimum rear-foot angle (deg) while walking at 3.5 mph, mean (SD)

Boot	No load	60 lb load
P2	-3.25 [a] (3.19)	-2.22 [a] (3.71)
P3	-5.05 [a] (4.05)	-4.77 [a,b] (4.52)
P4	-4.89 [a] (8.59)	-5.28 [b] (8.70)
MC	-4.35 [a] (3.29)	-3.75 [a,b] (2.88)
AC	-6.19 [a] (5.85)	-6.37 [b] (5.69)
AJ	-4.28 [a] (5.69)	-4.42 [a,b] (5.48)

Different letters indicate significant differences ($p \leq 0.05$)
A negative angle indicates supination, while a positive angle indicates pronation

Excessive pronation during walking or running is generally considered a major risk factor for lower extremity injury. The degree of pronation is shown in Table 14 as the maximum rear-foot angle. It can be seen that there was no significant difference between the boots in pronation during unloaded walking. However, boot P2 produced the greatest amount of pronation during loaded walking.

Table 14. Maximum rear-foot angle (deg) while walking at 3.5 mph, mean (SD)

Boot	No load	60 lb load
P2	8.45 [a] (4.11)	10.22 [a] (4.09)
P3	8.49 [a] (3.68)	9.10 [a,b] (3.79)
P4	7.72 [a] (5.80)	7.40 [a,b] (4.88)
MC	7.55 [a] (4.03)	7.98 [a,b] (4.81)
AC	4.99 [b] (5.78)	6.53 [b] (5.68)
AJ	7.66 [a] (3.57)	7.11 [b] (7.64)

Different letters indicate significant differences ($p \leq 0.05$)
A negative angle indicates supination, while a positive angle indicates pronation

Table 15 shows the average rear-foot angle during walking. Because a positive angle means pronation, and a negative angle supination, it can be seen that, on average, the foot was close to a neutral position, neither pronated nor supinated. However, boot P2 produced clear pronation, particularly under the loaded condition.

Table 15. Average rear-foot angle (deg) while walking at 3.5 mph

Boot	No load	60 lb load
P2	1.61 [a] (2.60)	3.60 [a] (3.09)
P3	-0.11 [a,b] (2.71)	-0.02 [b] (3.31)
P4	0.29 [a,b] (4.40)	0.17 [b] (4.70)
MC	-0.08 [a,b] (2.61)	-0.20 [b] (2.81)
AC	-1.22 [b] (4.72)	-1.40 [b] (4.14)
AJ	-0.39 [b] (4.38)	-0.36 [b] (5.48)

Different letters indicate significant differences ($p \leq 0.05$)

Excessive rear-foot motion during walking is not considered desirable. The standard deviation of rear-foot angle provides a measure of the variability of the rear-foot angle. Table 16 shows that all of the boots produced standard deviations of rear-foot angle of 2-3 degrees. There were no significant differences among the boots as to standard deviation of rear-foot motion during either loaded or unloaded walking.

Table 16. Within trial standard deviation of rear-foot angle (deg) while walking at 3.5 mph, mean (SD)

Boot	No load	60 lb load
P2	2.64 [a] (0.76)	2.75 [a] (1.03)
P3	2.74 [a] (0.99)	2.84 [a] (1.15)
P4	2.88 [a] (2.67)	2.81 [a] (2.25)
MC	2.53 [a] (0.90)	2.52 [a] (0.99)
AC	2.40 [a] (1.12)	2.78 [a] (1.26)
AJ	2.70 [a] (1.32)	2.65 [a] (1.15)

Different letters indicate significant differences ($p \leq 0.05$)

Range of rear-foot angular motion is another measure of how much frontal plane ankle motion the boots allowed. Table 17 shows that the boots produced rear-foot ranges of motion between 11 and 14 degrees. There were no significant differences among the boots as to range of rear-foot motion during either loaded or unloaded walking.

Table 17. Range of rear-foot motion (deg) while walking at 3.5 mph, mean (SD)

Boot	No load	60 lb load
P2	11.70 [a] (3.52)	12.44 [a] (4.84)
P3	13.54 [a] (5.04)	13.87 [a] (4.67)
P4	12.60 [a] (9.78)	12.69 [a] (7.82)
MC	11.89 [a] (4.55)	11.73 [a] (5.58)
AC	11.18 [a] (5.59)	12.90 [a] (5.83)
AJ	11.94 [a] (5.24)	11.54 [a] (5.18)

Different letters indicate significant differences ($p \leq 0.05$)

Kinetics. It is apparent that higher forces on the body during walking are more likely to produce injury than lower forces. Therefore, the forces experienced by the major lower body joints are an important measure of a boot's effectiveness. Tables 18-20 respectively show the maximum forces on the ankle, knee, and hip while walking at 3.5 mph both with and without a load. During both loaded and unloaded walking, boot MC produced the highest forces on both the ankle and knee. Boot MC also produced the highest force on the hip during loaded walking. For unloaded walking, boot AJ produced the highest forces on the hip.

Table 18. Maximum force on the ankle (N) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	966.3[b] (84.4)	981.3[a,b] (71.9)	981.7[a,b] (64.9)	997.9[a] (84.0)	976.6[a,b] (90.2)	986.4[a,b] (94.3)
60 lb pack	1290.5[b] (98.9)	1292.5[b] (83.9)	1294.1[b] (75.1)	1333.2[a] (126.7)	1289.5[b] (92.9)	1299.7[b] (86.0)

Different letters indicate significant differences ($p \leq 0.05$)

Table 19. Maximum force on the knee (N) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	927.2[b] (86.1)	942.8[a,b] (74.9)	943.6[a,b] (69.2)	954.3[a] (89.0)	939.1[a,b] (93.9)	947.2[a,b] (99.5)
60 lb pack	1250.4[b] (99.0)	1251.3[b] (85.1)	1254.2[b] (74.1)	1290.2[a] (128.1)	1252.1[b] (96.4)	1262.7[b] (91.7)

Different letters indicate significant differences ($p \leq 0.05$)

Table 20. Maximum force on the hip (N) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	850.8[b] (93.8)	865.3[a,b] (83.2)	868.8[a,b] (81.1)	872.6[a,b] (103.5)	870.5[a,b] (111.5)	876.8[a] (116.2)
60 lb pack	1169.8[b] (103.4)	1170.4[b] (90.8)	1175.8[b] (74.4)	1211.3[a] (141.3)	1181.1[b] (109.3)	1193.2[a,b] (114.4)

Different letters indicate significant differences ($p \leq 0.05$)

During walking, the heel is the foot's first point of contact with the ground (Chan and Rudins, 1994; Hughes and Jacobs, 1979). The forces transmitted from the ground to the body at heel-strike are usually the highest forces on the body during the entire stride, and are transmitted up the body through the skeletal system. Therefore, an important measure of a boot's effectiveness is the degree to which it can attenuate the forces at heel-strike. Table 21 shows maximum vertical heel-strike forces during walks at 3.5 mph both with and without a load. During both loaded and unloaded walking, boot MC produced the highest vertical heel-strike forces, as it did for the joint forces in the tables above.

Table 21. Maximum heel-strike vertical force (N) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	953.5[b] (88.0)	962.0[a,b] (83.3)	968.3[a,b] (79.6)	982.2[a] (91.3)	954.6[b] (102.9)	967.7[a,b] (97.9)
60 lb pack	1279.1[b] (98.5)	1274.3[b] (88.6)	1265.21[b] (100.2)	1317.2[a] (125.9)	1266.0[b] (108.2)	1269.8[b] (97.2)

Different letters indicate significant differences ($p \leq 0.05$)

When the foot strikes the ground during walking, it exerts some forward force on the ground, and the ground reacts with equal and opposite rearward force, acting to decelerate or brake the walker. These forces are shown in Table 22. It can be seen that the braking forces are on the order of 20% of the vertical forces, both with and without a load. Thus the braking forces are not as potentially injurious as are the vertical ground reaction forces. While there were no significant differences between boots as to heel-strike braking force during unloaded walking, boots P2 and MC produced the highest braking force during loaded walking.

Table 22. Maximum heel-strike braking force (N) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	185.6[a] (35.0)	183.6[a] (37.7)	187.1[a] (30.1)	196.1[a] (36.7)	190.7[a] (35.4)	187.3[a] (38.8)
60 lb pack	286.3[c] (46.4)	269.3[a,b] (38.7)	273.1[b,c] (41.0)	286.2[c] (58.6)	264.0[a,b] (46.6)	255.1[a] (42.4)

Different letters indicate significant differences ($p \leq 0.05$)
There was a significant ($p<=0.05$) boot by load interaction

It is more difficult to place a value judgment on maximum vertical push-off force than on maximum vertical heel-strike force. It is clear that lower heel-strike force is desirable because it results in less shock to the body as the heel strikes the ground. However, low push-off force may not be as desirable because it translates into reduced acceleration. Thus the benefit of lower maximum push-off force is reduced force transmitted through the musculoskeletal system, but the drawback may be reduced ability to accelerate the body. Looking at maximum vertical push-off force (Table 23), under the no-load condition there were no significant differences between the boots. However, during loaded walking, boots AC and AJ produced the highest vertical push-off forces. Maximum vertical push-off force was on the order of 94% of maximum vertical heel-strike force, for both unloaded and loaded walking.

Table 23. Maximum vertical push-off force (N) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	905.1[a] (86.0)	909.0[a] (80.3)	917.3[a] (81.7)	902.3[a] (88.4)	913.1[a] (93.7)	911.9[a] (90.9)
60 lb pack	1187.8[a,b] (93.5)	1175.0[b] (98.3)	1197.4[a,b] (89.6)	1185.6[a,b] (101.0)	1206.4[a] (77.9)	1204.4[a] (83.2)

Different letters indicate significant differences ($p \leq 0.05$)

Maximum push-off horizontal forces (Table 24) are on the order of 20% of the maximum push-off vertical forces, both with and without a load. Notably, boot MC produced the lowest horizontal push-off forces both with and without a load, suggesting that the boot might negatively affect the ability of the soldier to accelerate rapidly. It is notable that while maximum push-off horizontal force during unloaded walking was about 94% of maximum heel-strike horizontal force, the same percentage that push-off vertical forces were of heel-strike vertical forces for both unloaded and loaded walking, maximum push-off horizontal force during loaded walking was only about 84% of maximum heel-strike horizontal force.

Table 24. Maximum horizontal push-off force (N) while walking at 3.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
No load	176.9[a] (31.5)	172.1[a,b] (23.3)	181.5[a] (29.9)	165.7[b] (27.8)	175.9[a] (24.1)	178.3[a] (21.4)
60 lb pack	228.8[a,b] (37.5)	221.0[b,c] (32.3)	230.8[a,b] (36.4)	214.2[c] (38.7)	237.8[a] (26.2)	234.1[a] (23.9)

Different letters indicate significant differences ($p \leq 0.05$)

Kinematics and Kinetics of Jump Landing

When landing on the ground from a jump, effective shock absorption by a boot is critical for avoiding injury. Table 25 shows peak landing force values when jumping off a 24-inch high platform. Lower values indicate better shock absorption, and higher values poorer shock absorption. It can be seen that boots P3 and P4 produced the lowest peak landing force, while boot AC produced the highest peak landing force.

Table 25. Peak landing forces (N) after jumping off a 24-inch high platform, mean (SD)

P2	P3	P4	MC	AC	AJ
4872[c,d] (2077)	4662[d] (1351)	4526[d] (2176)	5318[b,c] (2233)	6234[a] (2056)	5723[a,b] (1865)

Different letters indicate significant differences ($p \leq 0.05$)

Looking at average landing force after jumping off a 24-inch high platform (Table 26), it can be seen that there were no statistically significant differences among the boots.

Table 26. Average landing force (N) after jumping off a 24-inch high platform, mean (SD)

P2	P3	P4	MC	AC	AJ
1022[a] (343)	957[a] (296)	966[a] (370)	993[a] (365)	1029[a] (356)	963[a] (379)

Different letters indicate significant differences ($p \leq 0.05$)

Table 27 shows that peak landing acceleration after jumping off a 24 in high platform was in the 57-77 m/s^2 range, equivalent to 6-8 g's. The 3 prototype boots produced the lowest peak landing accelerations, while boot AC produced the highest peak landing acceleration.

Table 27. Peak landing acceleration (m/s^2) after jumping off a 24-inch high platform, mean (SD)

P2	P3	P4	MC	AC	AJ
59.60[c] (24.67)	58.03[c] (15.86)	56.68[c] (25.38)	64.87[b,c] (26.32)	76.87[a] (24.21)	69.81[a,b] (21.89)

Different letters indicate significant differences ($p \leq 0.05$)

Motion Analysis of Running at 6.0 Miles Per Hour

Kinematics. Maximum front-back acceleration of the body center-of-mass while running (Table 28) is a variable on which it is difficult to place a value judgment. On one hand, lower front-back accelerations suggest less jarring to the body and possibly greater efficiency. On the other hand, higher front-back accelerations suggest the ability to both stop and accelerate more rapidly, which can be useful and even life-saving on the battlefield. Boot P4 produced the highest maximum front-back acceleration, while boot MC produced the lowest maximum front-back acceleration. Support for the notion of an association between low maximum front-back acceleration during sub-maximal running and reduced ability to accelerate during maximal-speed running is supported by the fact that boot MC had the lowest maximum front-back acceleration during sub-maximal running, and the slowest run times for the 400 m maximal speed grass runs. Also, boot P4, which had the highest maximum front-back accelerations, was quite fast on the grass runs. The notion that greater maximum front-back acceleration might reduce efficiency is belied by the fact that the boots showed no difference in oxygen consumption during unloaded running at 6.0 mph. In balance, the evidence suggests that higher maximum front-back acceleration during sub-maximal running has more positive than negative implications.

Table 28. Maximum front-back acceleration of the body center-of-mass (m/s^2) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
14.4[a,b] (4.29)	15.4[a,b] (5.53)	16.8[a] (5.76)	13.6[b] (5.36)	16.0[a,b] (6.15)	15.5[a,b] (7.17)

Different letters indicate significant differences ($p \leq 0.05$)

While there were significant differences between boots as to stride length while walking, the boots produced no significant differences in stride length while running as seen in Table 29. While the stride length during walking at 3.5 mph was about 1.7 m, the stride length during running was about 2.4 m, an increase of about 40%.

Table 29. Stride Length (m) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
2.418[a] (0.17)	2.352[a] (0.18)	2.402[a] (0.25)	2.435[a] (0.16)	2.427[a] (0.22)	2.386[a] (0.23)

Different letters indicate significant differences ($p \leq 0.05$)

Minimum sagittal plane ankle angle during running (Table 30) can indicate resistance of the boot to ankle dorsiflexion, a larger minimum angle indicating greater resistance because it means the ankle does not bend as much. The only boot that differed significantly from the others in this regard was boot MC, which produced the smallest ankle angle during running at 6.5 mph, just as it did for walking at 3.5 mph. This suggests that boot MC offered the least resistance to ankle dorsiflexion.

Table 30. Minimum sagittal plane ankle angle (deg) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
91.3[a] (7.5)	91.8[a] (6.7)	92.3[a] (7.2)	87.4[b] (7.0)	90.7[a] (5.4)	93.4[a] (5.1)

Different letters indicate significant differences ($p \le 0.05$)

The greater ankle dorsiflexion produced by boot MC might suggest that the boot is somewhat less resistant than the other boots to ankle movement in the sagittal plane. However, that notion is contradicted by the data in Table 31, which shows that there was a 3-way tie for greatest sagittal plane ankle range of motion among boots P2, P3, and MC. Boot P4 appears the most restrictive to sagittal plane ankle motion, producing a range of motion of less than 44º

Table 31. Sagittal plane ankle angle range (deg) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
46.8[a] (3.66)	47.0[a] (3.10)	43.7[c] (4.31)	46.7[a] (3.63)	46.1[a,b] (4.16)	44.8[b,c] (4.37)

Different letters indicate significant differences ($p \le 0.05$)

Kinetics. It is apparent that higher forces on the body during running are more likely to produce injury than lower forces. Therefore, the forces experienced by the major lower body joints are an important measure of a boot's effectiveness. Tables 32-34 respectively show the maximum forces on the ankle, knee and hip during unloaded running at 6.5 mph. Boot P3 produced higher forces at all three of the lower body joints than did the other boots. The maximum forces at all 3 joints during running were about twice those during walking.

Table 32. Maximum force on the ankle (N) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
1899.0[a,b] (202.5)	1922.4[a] (218.2)	1868.2[b,c] (223.2)	1916.8[a,b] (230.8)	1845.7[c] (252.0)	1884.7[a,b,c] (211.4)

Different letters indicate significant differences ($p \leq 0.05$)

Table 33. Maximum force on the knee (N) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
1806.1[a,b] (200.7)	1836.0[a] (214.4)	1776.8[b,c] (219.5)	1821.5[a,b] (220.9)	1754.7[c] (240.5)	1791.7[a,b,c] (201.7)

Different letters indicate significant differences ($p \leq 0.05$)

Table 34. Maximum force on the hip (N) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
1614.1[b] (194.1)	1701.5[a] (240.0)	1635.8[b] (205.2)	1640.2[b] (207.4)	1585.8[b] (230.0)	1623.5[b] (198.9)

Different letters indicate significant differences ($p \leq 0.05$)

The vertical forces transmitted from the ground to the body during running are relatively high, and are transmitted up the body through the skeletal system. Therefore, an important measure of a shoe or boot's effectiveness during running is the degree to which it can attenuate these forces. As compared to walking, which is characterized by two distinct vertical force peaks, one at heel-strike and the other at push-off, not all runners demonstrate 2-peak patterns. Several of our running trials evidenced no clear heel-strike peak in that, rather than striking the ground initially with the heel, the volunteers made initial contact with a relatively flat foot.

Heel-strike force was, by necessity, only measured for those trials in which there were heel-strikes. Table 35 shows maximum heel-strike force during 6.5 mph running. It can be seen that the first force peak is in the vicinity of 83%-88% above body weight. There were no statistically significant differences among the boots for this variable.

Table 35. Maximum vertical heel-strike force (N) during 6.5 mph running, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
Magnitude (N)	1566.6[a] (333.5)	1549.6[a] (434.4)	1505.4[a] (364.9)	1536.5[a] (355.3)	1510.5[a] (463.3)	1511.5[a] (435.5)
% body weight	188.0[a] (31.0)	188.0[a] (40.9)	183.1[a] (34.1)	186.4[a] (35.0)	182.8[a] (44.3)	184.4[a] (43.5)

Data included only for those trials with a discernable heel-strike
Different letters indicate significant differences ($p \leq 0.05$)

When the foot strikes the ground during running, it exerts some forward force on the ground, and the ground reacts with equal and opposite rearward force, decelerating or braking the runner. These forces are shown in Table 36. It can be seen that the braking forces are on the order of 15% of the vertical forces (Table 35), in contrast to walking, for which the braking forces were about 20% of the vertical forces. Because they are relatively low in magnitude, the braking forces do not seem as relevant to injury prevention as the vertical forces. In contrast to unloaded walking, for which there were no significant differences between boots as to heel-strike braking force, boots P3 and P4 produced the highest braking forces during unloaded running.

Table 36. Maximum heel-strike braking force (N) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
248.6[a] (44.0)	290.4[c] (86.3)	300.4[c] (77.6)	255.1[a,b] (52.0)	276.9[b,c] (73.2)	280.2[b,c] (85.2)

Different letters indicate significant differences ($p \leq 0.05$)

As with walking, it is more difficult to place a value judgment on maximum push-off force during running than on maximum heel-strike force. It is clear that lower heel-strike force is desirable because it results in less shock to the body as the heel strikes the ground. However, low push-off force may not be as desirable because it translates into reduced acceleration. Thus the benefit of lower maximum push-off force is a reduction in force transmitted through the musculoskeletal system, but the drawback may be reduced ability to accelerate the body. Table 37 shows that the magnitude of the maximum vertical push-off force during running at 6.5 mph ranged from 231% to 238% of body weight. Boots P2, P3, and MC produced the highest such forces. Maximum vertical push-off force was about 25% greater in magnitude than maximum vertical heel-strike force. Boot MC produced the highest forces.

Table 37. Maximum vertical push-off force (N) while running at 6.5 mph, mean (SD)

Boot ➡	P2	P3	P4	MC	AC	AJ
Magnitude (N)	1902.1[a,b] (197.5)	1899.3[a,b] (205.4)	1868.6[b] (211.8)	1916.6[a] (224.1)	1856.1[b] (255.4)	1860.5[b] (228.4)
% body weight	237.1[a,b] (18.9)	235.9[a,b,c] (23.2)	231.9[b,c] (24.6)	237.9[a] (26.5)	231.2[c] (30.0)	230.8[c] (27.4)

Different letters indicate significant differences ($p \leq 0.05$)

Maximum push-off horizontal forces during running (Table 38) were on the order of 10% of the maximum push-off vertical forces. This is in contrast to walking, in which the horizontal push-off forces were about 20% of the vertical push-off forces. Boots P2, MC, and AC produced the highest horizontal push-off forces. It is notable that maximum horizontal push-off force during running ranged from 61%-83% of maximum heel-strike horizontal force, averaging 71%. This is in sharp contrast to walking, during which maximum push-off horizontal force averaged about 94% of maximum heel-strike horizontal force.

Table 38. Maximum push-off horizontal force (N) while running at 6.5 mph, mean (SD)

P2	P3	P4	MC	AC	AJ
207.1[a] (28.6)	181.0[b] (29.7)	181.5[b] (39.7)	201.4[a] (31.5)	202.9[a] (35.0)	183.9[b] (32.6)

Different letters indicate significant differences ($p \leq 0.05$)

Comfort and Injury Prevention

Tables 39 through 41 show the number of volunteers that made positive comments about various aspects of the boots. There was only one positive comment about the heel area of any of the boots, and that was a comment about good support by the heel for boot P3. None of the volunteers cited the toe box as among the best boot features.

Table 39 shows the number of volunteers that cited various aspects of the sole as among the best boot features. Boots MC and AC received the fewest number of positive comments about the sole.

Table 39. Number of volunteers that cited various aspects of the sole as among the best boot features

Comment	P2	P3	P4	MC	AC	AJ
Traction	1	3	4	3	3	5
Cushion	4		1			
Insole			2			
Soft/comfortable		2				
Thick	1					
Arch support		1				
Tread		1				

Table 40 shows the number of volunteers that cited various aspects of the uppers as among the best boot features. Boots P2 and MC received the fewest positive comments about the uppers.

Table 40. Number of volunteers that cited various aspects of the uppers as among the best boot features

Comment	P2	P3	P4	MC	AC	AJ
Flexibility	1		2			3
Ankle support		3	2	1	4	1

Table 41 shows the number of volunteers that cited miscellaneous aspects as among the best boot features. Boots P3 and AC had the least number of positive comments (3), while boot P4 had the greatest number of miscellaneous positive comments (10).

Table 41. Number of volunteers that cited miscellaneous aspects as among the best boot features

Comment	P2	P3	P4	MC	AC	AJ
Lightweight						1
Comfortable	3		4	3		
Breath well				1		3
Flexibility	1		2	1		
Support	2	3	2	1		
Fit			1		1	
Best boot so far			1			
Good for hard, flat surfaces	1					
Absorbed pounding of march					1	
Protected foot				1		
Stability					1	
Didn't come untied						1

Table 42 shows the total number of positive comments for each boot, ranging from a low of 10 for boot AC to a high of 21 for boot P4. Boot MC scored only slightly higher than boot AC with 11 positive comments.

Table 42. Total number of positive comments for each boot

Boot ➡	P2	P3	P4	MC	AC	AJ
Total	14	14	21	11	10	14

Tables 43 to 47 show the number of volunteers that cited various aspects of the boot as among the worst boot features. Complaints about the toe box are shown in Table 43. There were no more than 2 toe box complaints for any of the boots.

Table 43. Number of volunteers that cited various aspects of the toe box as among the worst boot features

Comment	P2	P3	P4	MC	AC	AJ
Narrow toe box						1
Wide toe box				1		
Toe box	1				1	
Blisters					1	1

Complaints about the sole are shown in Table 44. There were no sole complaints for boots P4, while the highest number of complaints about the sole was registered for boot AC, which tallied 6 complaints.

Table 44. Number of volunteers that cited various aspects of the sole as among the worst boot features

Comment	P2	P3	P4	MC	AC	AJ
Tread pattern	1					
Traction	3	1			1	
Tough soles		3			4	1
Arch support		1			1	
Too narrow				1		

Complaints about the uppers are shown in Table 45. Only boots P2 and AJ received complaints about the uppers, with boot P2 receiving the most complaints, at 6.

Table 45. Number of volunteers that cited various aspects of the uppers as among the worst boot features

Comment	P2	P3	P4	MC	AC	AJ
Ankle support	4					1
Slippery ankles	1					
Hard						1
Easy to twist ankles	1					

Complaints about the heel are shown in Table 46. The overall number of such complaints was low, with the highest number registered for boot AJ, at 3.

Table 46. Number of volunteers that cited various aspects of the heel area as among the worst boot features

Comment	P2	P3	P4	MC	AC	AJ
Poor cushioning						1
Heels	1				1	
Sore heels				1		1
Narrow heels						1

Complaints about miscellaneous factors are shown in Table 47. All of the boots received 3-5 miscellaneous complaints. All of the 5 complaints about boot MC were for being too hot. Boot AC was identified as being uncomfortable by 4 volunteers.

Table 47. Number of volunteers that cited miscellaneous factors as among the worst boot features

Comment	P2	P3	P4	MC	AC	AJ
Doesn't breath well			2			
Support	3	1			1	1
All features						1
Uncomfortable					4	1
Slippery cushioning			2			1
Average		1				
All around rubbing		1	1			
Hot				5		

Table 48 shows the total number of negative comments for each boot. Boots P2 and AC received the most negative comments, with 15 and 14 respectively.

Table 48. Total number of negative comments for each boot

Boot ➡	P2	P3	P4	MC	AC	AJ
Total	15	8	5	8	14	12

Table 49 shows the number of injuries to different regions of the foot subsequent to the 6-mile hike with a 60-lb backpack. All injuries consisted of chafing and blistering of the skin rather than injuries to bone, muscle, tendon, cartilage or ligament tissue. The fewest injuries occurred for boot P2 (21), while the most injuries occurred with boots MC and AJ, with 69 and 71 injuries respectively.

Table 49. Number of injuries* to different regions of the foot subsequent to a 6-mile hike with 60-lb backpack

Boot ➡	P2	P3	P4	MC	AC	AJ
Total	21	27	42	69	51	71
Lateral Border: Inferior Aspect	0	6	12	16	8	13
Medial Border: Inferior Aspect	6	12	22	46	22	22
Forefoot: Inferior Aspect	2	17	31	59	26	33
Heel: Inferior Aspect	0	2	0	0	0	2
Forefoot: Superior Aspect	9	0	0	3	11	11
Heel: Inferior, Posterior, Medial, Lateral	4	7	4	1	8	13
Ankle: Medial & Lateral	0	1	1	0	0	0
Lateral Aspect of Foot	0	1	1	3	3	8
Medial Aspect of Foot	2	1	3	0	1	8

* All injuries consisted of chafing and blistering of the skin rather than injuries to bone, muscle, tendon, cartilage, or ligament tissue.

As seen in Table 50, there were a fair number of complaints of foot or ankle pain, soreness, or discomfort subsequent to the march. Each of the boots elicited complaints from between 42% and 75% of the volunteers. Boots AC and AJ produced the most complaints, from fully ¾ of the volunteers.

Table 50. Number of volunteers reporting foot or ankle pain, soreness, or discomfort subsequent to the march

Boot	Number of volunteers
P2	5
P3	5
P4	6
MC	6
AC	9
AJ	9

Table 51 shows the number of volunteers reporting too little or too much width in various segments of the boot. Boot AJ produced by far the most complaints in this regard, with a total of 17 complaints, most due to excess narrowness in the toe-box, mid-foot, and fore-foot, and excessive width in the heel. None of the other boots produced consistent complaints.

Table 51. The number of volunteers reporting too little or too much width in various segments of the boot

	Toe Box		Fore-foot		Mid-foot		Heel	
Boot	Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow
P2	1	1	1	1	0	0	1	0
P3	0	0	1	0	0	0	1	0
P4	2	0	1	0	1	0	2	0
MC	1	1	1	1	1	0	0	1
AC	0	2	0	1	0	0	0	0
AJ	1	5	0	4	0	2	4	1

Inadequate toe box height can be associated with injury to the toe nails. Table 52 shows that each of the boots elicited complaints of inadequate toe-box height from 42%-67% of the volunteers. Boot AC was the worst in this regard, producing such complaints from fully 2/3 of the volunteers.

Table 52. Number of volunteers reporting inadequate toe box height

Boot	Frequency of responses
P2	5
P3	5
P4	6
MC	5
AC	8
AJ	6

Table 53 shows the number of volunteers reporting pain or soreness in various parts of the leg during the 6-mile 60-lb backpack hike. Boot AJ produced the most such complaints (6), while boot P3 produced the least, with only 1 such complaint.

Table 53. Number of volunteers reporting pain or soreness in various parts of the leg during the 6-mile 60-lb backpack hike

Boot	Pain front lower leg	Pain back lower leg	Pain front knee	Pain back knee	Pain front thigh
P2	2	0	2	0	1
P3	1	0	0	0	0
P4	1	1	0	0	1
MC	1	1	1	0	1
AC	0	0	1	1	0
AJ	1	1	1	0	3

Table 54 shows the number of volunteers reporting they slipped or fell on either rocky surfaces, branches, or roots. The boots performed well overall in this regard, with only two boots producing reports of slips or falls. Boot MC produced the most, with 2 such reports.

Table 54. Number of volunteers reporting they slipped or fell on either rocky surfaces or branches/roots

Boot	Slip rocky surface	Slip fallen tree branches
P2	0	0
P3	0	0
P4	0	0
MC	1	1
AC	0	1
AJ	0	0

Volunteer perceptions of inadequate traction on dirty or wet surfaces are shown in Table 55. It is interesting that boot P2 produced 4 complaints about inadequate traction, even though it produced no reports of slips or falls. Boot MC received no complaints about inadequate traction, despite producing 2 reports of slips or falls.

Table 55. Number of volunteers reporting inadequate traction on dirty or wet surfaces

Boot	Rock	Wet
P2	2	2
P3	1	0
P4	0	0
MC	0	0
AC	1	0
AJ	0	0

Some boot tread patterns can trap dirt, mud, or stones. Table 56 shows the number of volunteers reporting collection of dirt, mud, or stones in the boot tread. Boot P2 was the only boot that produced no reports concerning collection of mud in the tread. The rest of the boots produced 1-2 such complaints each.

Table 56. Number of volunteers reporting collection of dirt, mud, or stones in the boot tread

Boot	Frequency of responses
P2	0
P3	2
P4	2
MC	2
AC	1
AJ	2

One of the major functions of hiking boots is to protect the bottom of the foot from point pressures due to rocks and stones. Table 57 shows the number of volunteers reporting they felt rocks and stones through the boot heel or sole while hiking. Boot AC stands out as the worst boot in this regard, with 8 of the 11 volunteers reporting they felt rocks and stones through the boot. None of the other boots produced more than 3 such complaints.

Table 57. Number of volunteers reporting they felt rocks and stones through the boot heel or sole while hiking

Boot	Frequency of responses
P2	1
P3	1
P4	2
MC	2
AC	8
AJ	3

Overall boot discomfort is reported in Table 58. It is noteworthy that both current-issue Army boots (AC and AJ) produced far more complaints about severe discomfort than any of the other boots. About half of the volunteers felt these boots were very uncomfortable, while no more than 1 volunteer had such complaints about any of the other boots.

Table 58. Number of volunteers reporting the boots very uncomfortable during the march.

Boot	Very uncomfortable
P2	1
P3	1
P4	0
MC	1
AC	6
AJ	5

Lack of boot sole flexibility can be unpleasant during hiking. Table 59 shows that boot P2 produced no complaints at all about inflexibility. The remaining boots produced between 1 and 3 such complaints

Table 59. Number of volunteers reporting the boot soles inflexible

Boot	Not flexible
P2	0
P3	3
P4	1
MC	2
AC	3
AJ	3

Boot uppers can also be a source of inflexibility. Table 60 shows the number of volunteers reporting the boot uppers inflexible. The only boot receiving reports of upper inflexibility was boot AJ, which received 2 such complaints.

Table 60. Number of volunteers reporting the boot uppers inflexible

Boot	Not Flexible
P2	0
P3	0
P4	0
MC	0
AC	0
AJ	2

Table 61 shows information that should be considered among the most important in evaluating a boot, that is the number of volunteers that would not recommend the boots for use by the Army as field boots because of drawbacks in comfort and/or function. It is striking that more than 2/3 of the volunteers could not recommend the current-issue Army combat boot, and more than half could not recommend the current-issue Army jungle boot. Boots P4 and MC scored best in this regard, with only 1 volunteer who could not recommend each of the boots.

Table 61. Number of volunteers that, based only on comfort and function, would not recommend the boots for use by the Army as field boots

Boot	Frequency of responses
P2	3
P3	3
P4	1
MC	1
AC	8
AJ	6

Friction between the boot lining and the foot can cause discomfort as well as injury to the skin. Table 62 shows that boot AJ produced the most complaints by far, 13 in all. Boot AC produced the next-highest number of such complaints, with 7. Boot P4 scored the best in this regard, with no complaints of chafing at all.

Table 62. The number of volunteers reporting chafing by the boot lining at various parts of the foot

	Toe box Discomfort		Forefoot Discomfort		Heel Discomfort		Ankle Discomfort		
Boot	Top under surface	Outside surface	Top under surface	Inside surface	Inside surface	Outside surface	Top under surface	Inside surface	Outside surface
P2	1	0	0	0	1	1	0	0	0
P3	0	0	0	0	1	0	0	0	0
P4	0	0	0	0	0	0	0	0	0
MC	2	0	0	1	0	0	0	0	0
AC	2	1	1	0	0	0	1	1	1
AJ	2	1	5	1	1	1	1	0	1

A SYSTEM FOR OVERALL BOOT EVALUATION

It is difficult to compare the overall effectiveness of the 6 boots by examining all of the tables presented in the results section. Therefore, a point system was devised in which each boot would receive points for the variables deemed most critical to overall boot evaluation. The selected variables are listed below. The criterion for selection of variables was that a clear value judgment about the effectiveness of the boots could be made based on comparison of variable means. In other words, it had to be clear whether a variable indicated something positive or negative about the boot, and whether a high score or a low score was desirable. Another criterion for selection of a variable for the point system was that there were statistical differences between the boots. Point values were assigned based on the post hoc statistical analysis. To do this, the boots were ranked according to the letters or set of letters assigned to them in the post hoc analysis, in which different letters indicated significantly different means. A rank of 1 was always best. Several of the boots often received the same ranking, so that scores sometimes ranged from 1-3 and other times from 1-6 etc. In order to avoid weighing some of the variables more heavily than others, the rankings were multiplied or divided by a factor such that the scores for each variable had a maximum value of about 20.

To allow space for data in Table 63, which summarizes the overall evaluation, the names of variables used are abbreviated. However the abbreviated names are accompanied in the table by letters, which can be used to find the full name of each variable from the following list:

A. 400 m straight run times with load
B. Maximum vertical heel-strike force (N) while walking at 3.5 mph, unloaded
C. Maximum vertical heel-strike force (N) while walking at 3.5 mph, loaded
D. Maximum rear-foot angle (deg) while walking at 3.5 mph, unloaded
E. Maximum rear-foot angle (deg) while walking at 3.5 mph, loaded
F. Peak landing force after jumping down from a 24-inch high platform
G. Maximum heel-strike vertical force while running at 6.5 mph
H. Total number of positive comments for each boot
I. Total number of negative comments for each boot
J. Number of injuries to the foot subsequent to 6-mile hike
K. Number of volunteers reporting foot or ankle pain or soreness or discomfort subsequent to the march
L. Number of volunteers reporting pain or soreness in various parts of the leg during the 6-mile 60-lb backpack hike
M. Number of volunteers reporting they slipped or fell
N. Number of volunteers reporting inadequate traction on dirty or wet surfaces
O. Number of volunteers reporting collection of dirt, mud or stones in the boot tread
P. Number of volunteers that felt rocks and stones through the boot heel or sole while hiking

Q. Number of volunteers reporting the boots very uncomfortable during the march
R. Number of volunteers that would not recommend the boots
S. The number of volunteers reporting chafing by the boot

Table 63 shows the points assigned to each boot in the overall evaluation (lower is better). The next to last row in the table gives the total score for each boot. The last row gives a $base_{100}$ score computed such that the poorest performing boot would score 50 and the best performing boot 100. The calculation used to get the $base_{100}$ score was as follows:

$$base_{100}\ score = 100 - 50\frac{(\text{individual boot total score - best boot total score})}{(\text{worst boot total score - best boot total score})}$$

$$= 100 - 50(\text{individual boot total score-151})/(244\text{-}151)$$

It can be seen that prototype boot 4 (Boot P4) was the best boot overall with a $base_{100}$ score of 100. Based on their scores the boots are ranked as follows, from best to worst:

$Base_{100}$ Scores (100 is best, lower scores are not as good)

Rank	Boot	Score
1.	Prototype 4 (boot P4)	100
2.	Prototype 3 (boot P3)	88
3.	Prototype 2 (boot P2)	79
4.	Army combat boot (boot AC)	61
5.	Army jungle boot (boot AJ)	51
6.	Marine Corps boot (boot MC)	50

Based upon the large differences between the scores of the prototype boots and the current-issue boots, the prototype boots do appear to be clear improvements over the current-issue Army and Marine Corps boots.

Table 63. Points assigned to each boot in overall evaluation (lower is better)

Variable	P2	P3	P4	MC	AC	AJ
A. 400 m straight run time with load	12	12	12	18	6	6
B. Max v heel-strike force, unloaded walking	6	12	12	18	6	12
C. Max v heel-strike force, loaded walking	10	10	10	20	10	10
D. Max rear-foot angle, unloaded walking	20	20	20	20	10	20
E. Max rear-foot angle, loaded walking	18	12	12	12	6	6
F. Peak landing force, 24" jump down	8	4	4	12	20	16
G. Max forces on knees and hips, running	16	20	8	16	4	12
H. Total positive comments	16	16	9	19	20	16
I. Total negative comments	15	8	5	8	14	12
J. No. of hiking injuries	6	8	12	19	14	20
K. No. of foot pain reports	10	10	12	12	18	18
L. No. of leg pain reports	15	3	9	12	6	18
M. No. of slips and falls	0	0	0	20	10	0
N. No. of reports of inadequate traction	20	5	0	0	5	0
O. No. of dirt collection reports	0	20	20	20	10	20
P. No. of rock sensation reports	2	2	4	4	16	6
Q. No. of reports of severe discomfort	3	3	0	3	18	15
R. No. of vols. who would not recommend	6	6	2	2	16	12
S. No. of chafing reports	5	2	0	5	11	20
Total score (lower is better)	188	173	151	240	220	239
Base$_{100}$ score (higher is better)	79	88	100	50	61	51

For each variable, each boot was assigned points according to the statistical results, such that lower scores were better and higher scores worse. Scores for each variable were adjusted by a multiplication factor to fall within an approximate range of 0-20. The base$_{100}$ score was calculated so that the best boot would score 100 points and the worst boot 50 points, as described in the text. It must be emphasized that the scores reported in this table only show the boots' performances relative to each other. These scores cannot be compared to those in our previous boot study (10).

DISCUSSION

Many significant differences were found among the boots as to variables that reflect the boots' effectiveness in preventing injury and enhancing performance. The extensive data produced by the experiment should enable fact-based decisions about military boot design and selection.

The variables addressed in this experiment covered most of the three levels of requirements of military boots specified by Hamill and Bensel (6). The 400 m straight and zigzag runs with and without a load addressed the locomotor capabilities of the wearer. The oxygen uptake tests for loaded and unloaded walking, and unloaded running, addressed the efficiency of locomotion. The tabulation of injuries addressed the goal of minimizing the occurrence of lower extremity injury and pain. The requirement of providing comfort was assessed by the questions the volunteers answered about each boot after the 6 mile backpack march. Information was provided as well on the weight of the boots and how high they come up the ankle. This study did not address such military boot requirements as water resistance, durability of the uppers and soles, and limitations on unit cost or other production factors. These factors must be considered in a boot selection process along with the human-use tests of our study.

Despite the fact that, in their boot materials testing study, Hamill and Bensel (6), found the black leather combat boot and the hot weather jungle boot to show poorer impact attenuation than commercial footwear, as measured by peak deceleration, time to peak deceleration, and peak pressure, we found that these two current-issue boots did not show higher foot impact forces than the other boots during unloaded or loaded walking or unloaded running. That is likely because of subconscious gait adjustments the wearer makes in response to the hardness of the boot sole. Thus the hard soles of the current-issue military boots, as shown by materials testing, likely caused gait adjustments that reduced the impact force of the foot on the ground. These results are in contrast to the human testing of Hamill and Bensel (7,8) who found that the jungle and combat boots produced higher peak impact forces than commercial footwear, to which the prototype boots in the present study are more closely related. Our previous study comparing current-issue Army boots to both commercial and prototype boots (10) supports our current finding; the current-issue Army boots did not produce higher impact forces than either the prototype or commercial boots. In contrast to their findings for walking, Hamill and Bensel found no difference between the various boots for foot impact force during running, and sometimes lower impact for the military boots. In this regard, our results were similar to those of Hamill and Bensel.

Hamill and Bensel (9) showed no difference among footwear as to the heart rate or oxygen consumption of males. The results of this study were in agreement with that. That contrasts to our previous study on 12 boots, in which there were significant effects of boot type on the rate of oxygen consumption. Perhaps the absence of the commercial boots in the current study, some of which proved oxygen-efficient, and the modifications to the prototype boots from the previous to the present study, resulted in

the lack of significant differences between boots in oxygen consumption in the present study.

Williams et al. (18), who compared current-issue combat and jungle boots to commercially available boots, and a hybrid boot composed of the outer shell of the jungle boot and a non-standard polyurethane sole, found the best boots to be ones that are commercially available. Similarly, we found the prototype boots, which incorporate several features of commercial boots, to be clearly superior to the current-issue military boots. The conclusion of Williams et al. that optimal characteristics of commercially available boots can be combined to create a military prototype boot surpassing those in current use is in agreement with our findings.

We observed ground impact landing forces following a jump from a 24" (0.6 m) high box to be in the range of 6-7 times body weight. This is in the general range of the 6 times body weight landing forces observed by McNitt-Gray (14).

CONCLUSIONS

The following is the ranking (best to worst) of the boots tested according to the variables deemed most important:

Rank	Boot	Score
1.	Prototype 4 (boot P4)	100
2.	Prototype 3 (boot P3)	88
3.	Prototype 2 (boot P2)	79
4.	Army combat boot (boot AC)	61
5.	Army jungle boot (boot AJ)	51
6.	Marine Corps boot (boot MC)	50

It is important to note that the scores above are completely relative and can only be used to compare the boots in this study. It would not be meaningful to compare boot scores from this study to the scores of our previous study (10) or any other study.

The boots are discussed below in the order of their rankings, from best to worst:

- Prototype 4 (boot P4) was the best of the prototype boots. It was superior at absorbing shock during running and jump landings, traction, shielding from rocks and stones, and prevention of chafing. It received a lot of positive comments from the volunteers and few negative ones, as well as top comfort ratings and many recommendations. Its weaknesses were in allowing foot pronation during unloaded walking and collection of dirt in the tread.
- Prototype 3 (boot P3) was a good boot, performing very well at absorbing shock during jump landings, shielding from rocks and stones, traction, and prevention of chafing. It received few negative comments, high comfort ratings, and produced few hiking injuries or reports of leg pain. Its weaknesses were in allowing foot pronation during unloaded walking, poor shock absorption during running, few positive comments, and collection of dirt in the tread.
- Prototype 2 (boot P2) scored very well as to shock absorption during walking, avoidance of dirt collection in the tread, shielding from rocks and stones, and prevention of chafing. It had high comfort ratings and produced the fewest hiking injuries. Its weaknesses were in allowing foot pronation during both unloaded and loaded walking, poor shock absorption during running, few positive comments, several negative comments, reports of leg pain, and the worst traction of all the boots.

- The current-issue Army combat boot (boot AC) scored considerably lower than any of the prototype boots, providing strong justification for development of a new standard-issue Army boot. It did very well at 400 m run time with a load, shock absorption during unloaded walking, pronation avoidance during loaded walking, avoidance of shock while running, and traction. It produced few reports of leg pain. However, it scored poorly at shock absorption during jump landings, produced very few positive comments, but many complaints of foot pain. It was rated as extremely uncomfortable by over half of the volunteers, and more than 2/3 of the volunteers would not recommend the boot for Army use.
- The Army jungle boot (boot AJ) scored only 1 point above the lowest scoring boot. Its poor performance provides strong justification for developing a new hot weather Army boot. The boot scored well as to 400 m straight run with load, prevention of foot pronation during loaded walking, traction, and shielding from rocks and stones. However, it was poor at absorbing shock during jump landings, received few positive comments, produced the most hiking injuries, elicited a large number of complaints about foot and leg pain, collected dirt in the tread, and received the most chafing complaints.
- The Marine Corps boot (boot MC) was the lowest scoring boot of the 6 boots tested. It evoked few negative comments, and scored well as to traction, shielding from rocks and stones, comfort, and prevention of chafing. In addition, it would be recommended by all but 1 of the volunteers. However, it scored poorly on many other variables including 400 m run time with a load, attenuation of heel-strike force during both unloaded and loaded walking, pronation during unloaded walking, force on the knees and hips during running, prevention of slips, and collection of dirt in the tread. It produced several foot injuries and received relatively few positive comments.

Knowledge of which boot did the best on each test can help determine which features of each boot may be worthy of incorporation into a future military boot. Therefore, the best performer on each test for which a value judgment could be made is indicated below:

- The boots did not differ as to 400 m straight run time without load.
- Boots AC and AJ produced the fastest 400 m straight run times with a load.
- The boots did not differ as to 400 m zigzag run time either with or without the load.
- The boots did not differ as to rate of oxygen consumption for either loaded or unloaded walking or unloaded running.
- All boots except the Marine Corps boot (boot MC) produced the greatest sagittal plane ankle range of motion during both unloaded and loaded walking.
- Boot AC produced the lowest maximum rear-foot angle (the least pronation) during unloaded walking.
- Boots AC and AJ produced the lowest maximum rear-foot angle (the least pronation) during loaded walking.
- Boot P2 produced the lowest forces on the ankle during unloaded walking.
- All boots except the Marine Corps boot (boot MC) produced the lowest forces on the ankle during loaded walking.
- Boot P2 produced the lowest forces on the knee during unloaded walking.

- Boot P2 produced the lowest forces on the knee during unloaded walking.
- All boots except the Marine Corps (boot MC) boot produced the lowest forces on the knee during loaded walking.
- Boot P2 produced the lowest forces on the hip during unloaded walking.
- All boots except the Marine Corps boot (boot MC) and the Army Jungle Boot (boot AJ) produced the lowest forces on the hip during loaded walking.
- Boots P2 and AC produced the lowest maximum vertical heel-strike force during unloaded walking.
- All boots except the Marine Corps boot (boot MC) produced the lowest maximum vertical heel-strike force during loaded walking.
- Boots P3 and P4 produced the lowest peak landing forces after jumping off a 24-inch high platform.
- Boots P2, P3, and P4 produced the lowest peak landing acceleration after jumping off a 24-inch high platform.
- Boots P2, P3, and MC produced the greatest sagittal plane ankle angle range during running at 6.5 mph.
- Boot AC produced the lowest forces on the ankle and knee during running at 6.5 mph.
- All boots other than boot P3 produced the lowest forces on the hip during running at 6.5 mph.
- The boots did not differ as to maximum vertical heel-strike force during running at 6.5 mph.
- Boots P3 and P4 received the highest number of positive comments about the boot sole.
- Boots P4 and AC received the highest number of positive comments about the boot uppers.
- Boot P4 received the highest number of positive comments about miscellaneous aspects of the boot.
- Boot P4 received the highest total number of positive comments, 50% more than its closest competitor.
- Boots P3 and P4 had the lowest number of negative comments about the boot toe box.
- Boot P4 had the lowest number of negative comments about the boot sole.
- Boots P3, P4, MC, and AC had the lowest number of negative comments about the boot uppers.
- Boots P3 and P4 had the lowest number of negative comments about the boot heel area.
- Boots P2 and P3 had the lowest number of negative comments about miscellaneous aspects of the boot.
- Boot P4 had the lowest total number of negative comments.
- Boot P2 produced the lowest number of injuries.
- Boots P2 and P3 produced the fewest reports of foot or ankle pain, soreness, or discomfort subsequent to the march.
- Boot P3 produced the fewest width complaints.
- Boots P2, P3, and MC produced the fewest reports of inadequate toe box height.

- Boot P3 produced the fewest reports of pain or soreness in various parts of the leg during the 6-mile 60-lb backpack hike.
- Boots P2, P3, P4, and AJ produced the fewest reports of slipping or falling on either rocky surfaces or branches/roots.
- Boots P4, MC, and AJ produced the fewest reports of inadequate traction on dirty or wet surfaces.
- Boot P2 produced the fewest reports of dirt, mud, or stones collecting in the boot tread.
- Boots P2 and P3 received the fewest reports of rocks and stones felt through the boot heel or sole while hiking.
- Boot P4 received the fewest reports about being very uncomfortable during the march.
- Boot P2 received the fewest reports of inflexible boot soles.
- All the boots but boot AJ received the fewest reports of inflexible uppers.
- Boots P4 and MC had the smallest number of volunteers who would not recommend them as Army as field boots.
- Boot P4 produced the fewest reports of chafing.

RECOMMENDATIONS

Of the boots tested, the 3 prototypes, boots P2, P3, and P4, were markedly superior to the current-issue Army combat and jungle boots and the current-issue Marine Corps boot. Boot P4 was the best boot overall, by a good margin, and appears to be the best candidate of the boots tested for adoption by the Army. However, it is important to note that we did not perform some essential off-the-wearer tests on the boots, such as tests for resistance to wear, water, organic liquids, heat, flame, etc. Neither did we test how the boots function after being used for several months. Evidence from such tests should be combined with evidence from our experiments for overall boot evaluation.

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APPENDIX A

Boot Questionnaire and Foot Injury Recording Form

Boot Study Questionnaire

Subject ID #_______ DATE:__________

Boot Type:_________

COMFORT/DISCOMFORT RATINGS:

1) Did you experience any pain soreness or discomfort in your feet or ankles during the march?

YES______ NO_______

If NO go on to Question # 2.

If YES answer the following questions.

1A) Were the boots appropriate in length? YES___ NO___

If No were the boots too long? YES___ NO___
If No were the boots too short? YES___ NO___

If the boots were too short:

A) Did you feel that there was not enough room for your toes in the boot? YES___ NO___

B) Did you feel excess pressure on your heels while walking or running? YES___ NO___

1B) Indicate how this pair of boots fits your foot width-wise

	wide	neutral	narrow
Toe box	____	____	____
Forefoot area	____	____	____
Midfoot/instep area	____	____	____
Heel area	____	____	____

1D) Were the toe boxes of the boots high enough inside?

YES____ NO____

1E) Did the inside lining of the boot chafe or otherwise injure you or cause discomfort? YES___ NO___

If YES, where was the problem area:

Toe Box:	Top under surface	______
	Inside surface	______
	Outside surface	______
	Insole	______
Forefoot area:	Top under surface	______
	Inside surface	______
	Outside surface	______
	Insole	______
Midfoot/instep:	Top under surface	______
	Inside surface	______
	Outside surface	______
	Insole	______
Heel area:	Top under surface	______
	Inside surface	______
	Outside surface	______
	Insole	______
Ankle area	achilles area	______
	inner ankle bone	______
	outer ankle bone	______
	under boot laces	______

2. Did you experience any pain or soreness in your legs during the march?

YES_____ NO_____

If YES where did the soreness occur? ____________________

3. Did you slip or fall during the march? YES____ NO____

If YES what kind of surface were you walking/running on when the slip happened? Paved road____ dirt road____ rock____ Fallen tree branches_____

4. Indicate your opinion of the traction provided by these boots, (i.e. their ability to grip the ground and prevent you from slipping).

_____ Good traction

_____ Adequate traction

_____ Bad traction

If you found these boots to have inadequate traction what were the surface conditions (dirt, paved, rock, dry, wet, slimy) when you experienced the bad traction? ______________________

5. Did stones or dirt/mud collect in the tread of the heels or soles of these boots?

YES____ NO____

6. As you walked over rocks and stones could you feel them through the heeals or soles of these boots?

YES____ NO____

7. How comfortable were these boots to wear during the march?

_____ Very comfortable

_____ Neither comfortable or uncomfortable

_____ Very uncomfortable

8. How flexible were the soles of these boots?

Not flexible at all ____

Moderately flexible ____

Very flexible ____

9. How flexible were the uppers of these boots?

Not flexible at all ____

Moderately flexible ____

Very flexible ____

10. In terms of hiking what is the best feature of the boots you wore today?

____

____

11. In terms of hiking what is the worst feature of the boots you wore today?

____

____

12. Based only on comfort and function would you reccomend these boots for use by the Army as field boots?

YES____ NO____

If NO, explain why?

____

____

FOOT INJURY DATA FORM

DATE________________

NAME______________________________

Total No.	Left Foot	Total No.	Right Foot
______		______	
______		______	
______		______	
______		______	
______		______	
______		______	
______		______	
______		______	
______		______	

Blisters	(B)
Hot Spots	(HS)
Bruises	(BU)
Abrasions	(A)
Tinea Pedis	(TP)
Metatarsal Pain	(MP)
Dermatitis	(D)
Other________________